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Tiede et al.

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(54) **TRACK-MODULE BOGIE-SUSPENSION SYSTEM**

(71) Applicant: **ATI, Inc.**, Mt. Vernon, IN (US)

(72) Inventors: **Duane Tiede**, Naperville, IL (US); **Jamsheed Reshad**, Newburgh, IN (US); **Timothy D. Stacy**, Mt. Vernon, IN (US); **Kenneth J. Juncker**, Mt. Vernon, IN (US)

(73) Assignee: **ATI, Inc.**, Mt. Vernon, IN (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/625,248**

(22) Filed: **Feb. 18, 2015**

Related U.S. Application Data

(63) Continuation-in-part of application No. 14/625,229, filed on Feb. 18, 2015.

(51) **Int. Cl.**

B62D 55/04	(2006.01)
B62D 55/104	(2006.01)
B62D 55/112	(2006.01)
B62D 55/10	(2006.01)
B62D 55/084	(2006.01)
B62D 55/14	(2006.01)
B60G 11/27	(2006.01)
B60G 5/01	(2006.01)

(52) **U.S. Cl.**
CPC ***B62D 55/104*** (2013.01); ***B60G 5/01*** (2013.01); ***B60G 11/27*** (2013.01); ***B62D 55/0842*** (2013.01); ***B62D 55/10*** (2013.01); ***B62D 55/112*** (2013.01); ***B62D 55/14*** (2013.01); *B60G 2202/15* (2013.01)

(58) **Field of Classification Search**
CPC .. B62D 55/104; B62D 55/10; B62D 55/108; B62D 55/1083; B62D 55/1086; B62D 55/112; B62D 55/1125
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,094,794	A *	6/1963	Wardle	B62D 55/108	37/304
3,841,424	A *	10/1974	Purcell	B62D 55/08	180/9.5
4,874,052	A *	10/1989	Purcell	B60G 5/06	180/24.02
5,273,126	A *	12/1993	Reed	B62D 49/0635	180/9.21
5,316,381	A *	5/1994	Isaacson	B62D 55/305	305/145
5,340,205	A *	8/1994	Nagorcka	B62D 55/104	305/132
5,997,109	A *	12/1999	Kautsch	B62D 55/305	305/128
6,283,562	B1 *	9/2001	Tsubota	B62D 55/00	180/308

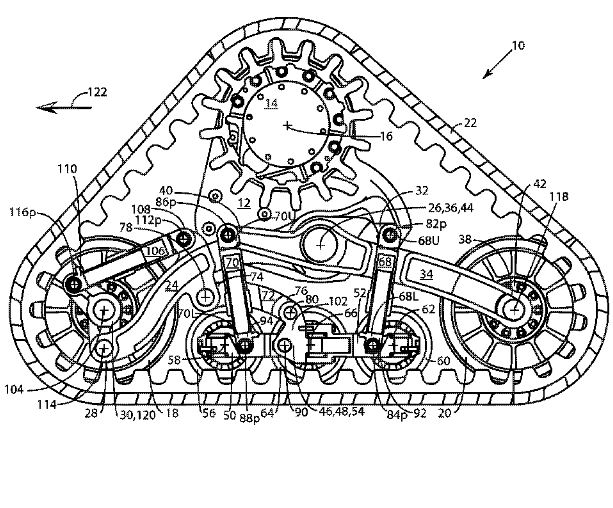
(Continued)

Primary Examiner — Kevin Hurley
Assistant Examiner — Marlon Arce
(74) *Attorney, Agent, or Firm* — Jansson Munger McKinley & Kirby Ltd.

(57) **ABSTRACT**

Track-module bogie-suspension apparatus for attachment to a track module having a frame, a drive wheel and an endless track. The bogie-suspension apparatus comprises (a) a bogie assembly having a bogie mount, at least one rotatable ground-engaging bogie wheel thereon, and forward and rearward bogie-mount connections; (b) first and second load- and ground-responsive suspension joints spaced from one another in a forward/rearward direction; and (c) leading and trailing suspension elements each having an upper end and a lower end, the upper ends of the leading and trailing suspension elements rotatably attached to the first and second suspension joints, respectively, and the lower ends thereof rotatably attached to the rearward and forward bogie-mount connections, respectively.

29 Claims, 23 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

7,628,235	B2	12/2009	Satzler et al.	
9,051,009	B2 *	6/2015	Prohaska	B62D 11/22
2004/0140138	A1 *	7/2004	Brazier	B62D 49/0635 180/9.21
2013/0154345	A1	6/2013	Schulz et al.	
2014/0125118	A1 *	5/2014	Nagorcka	B62D 55/14 305/125
2014/0138169	A1 *	5/2014	Fairhead	B62K 3/002 180/9.5
2015/0321708	A1 *	11/2015	Van Mill	B62D 55/06 280/28.5

* cited by examiner

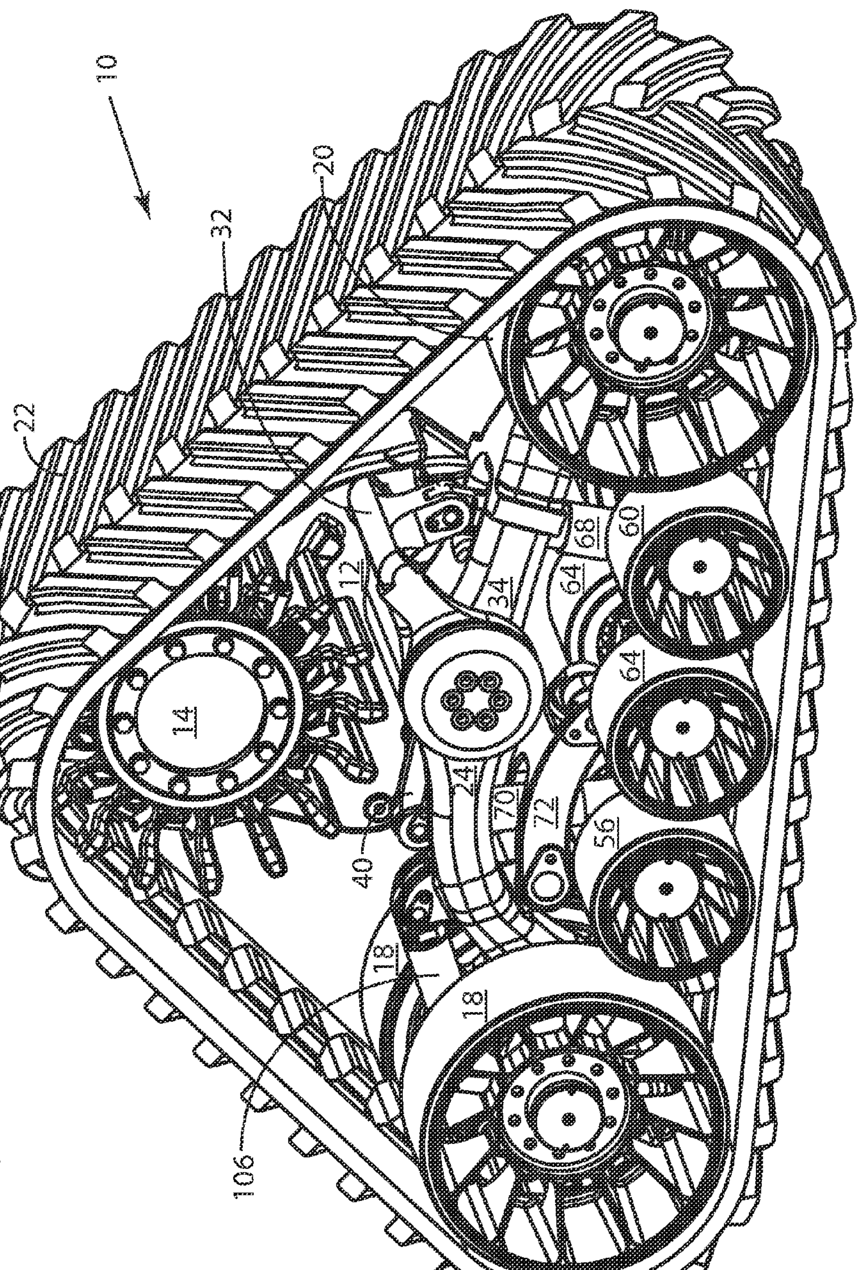


FIG. 1A

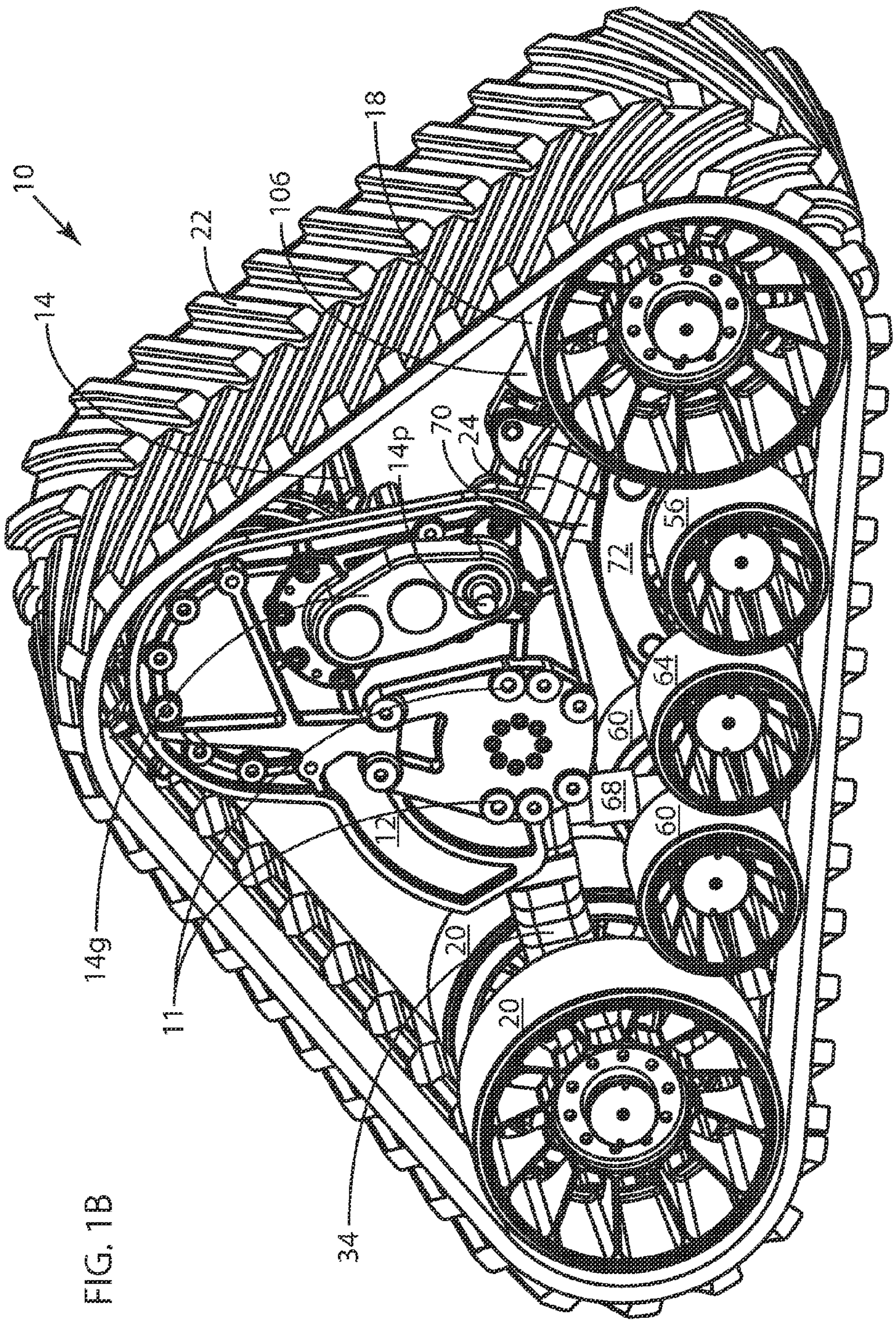
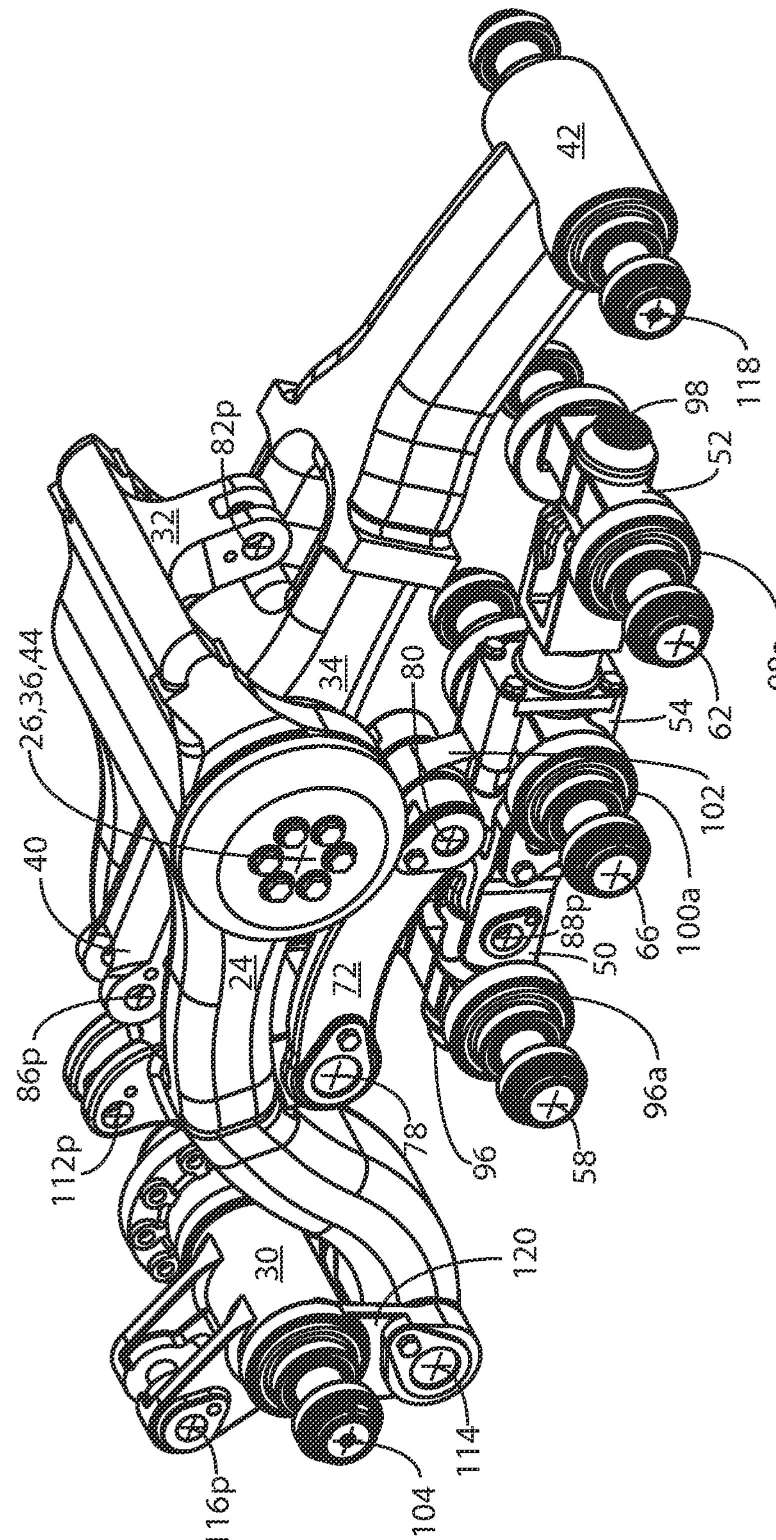


FIG. 1B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58
96
78
86p
112p
30
120
114
104
116p

FIG. 2

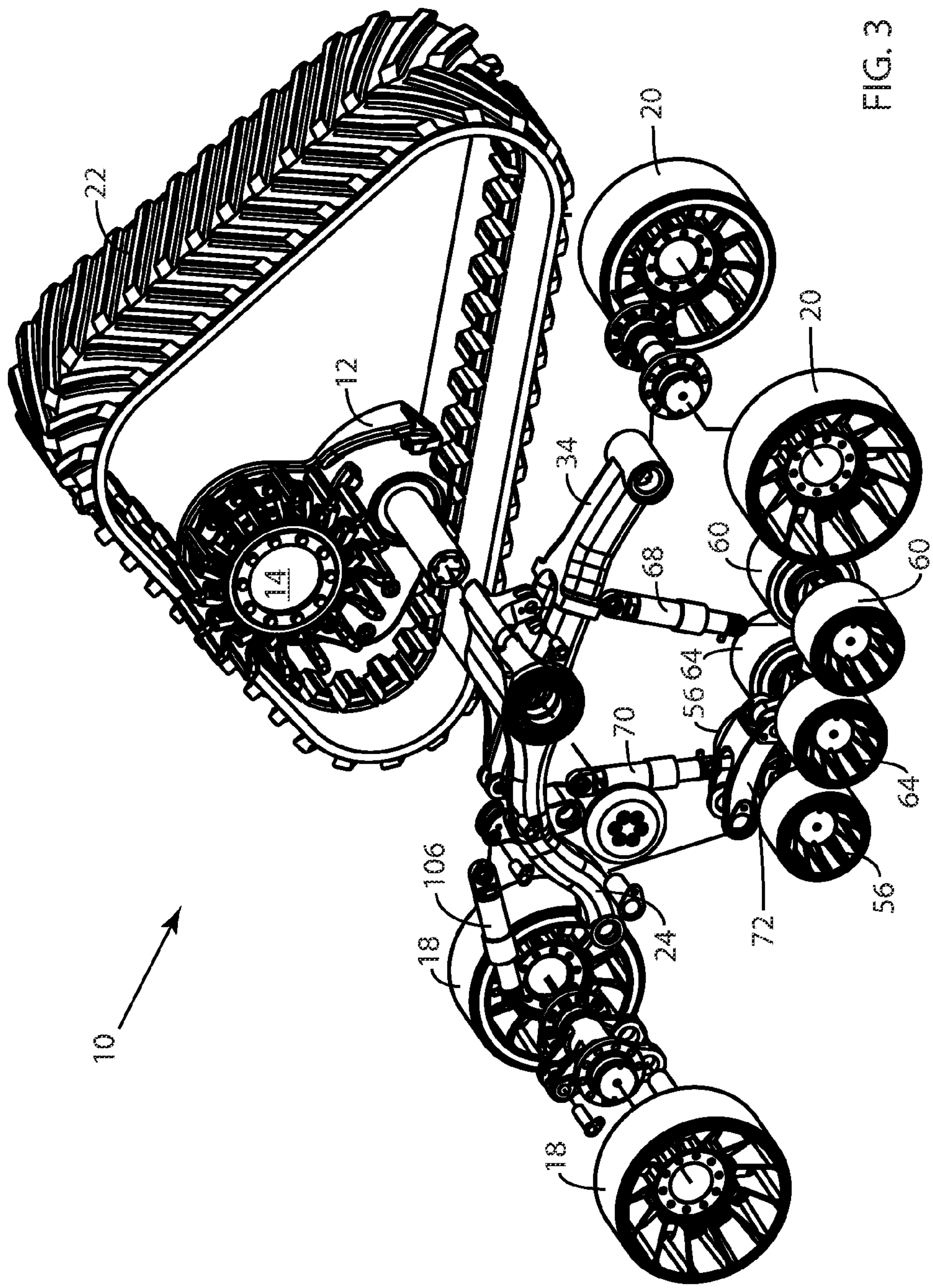
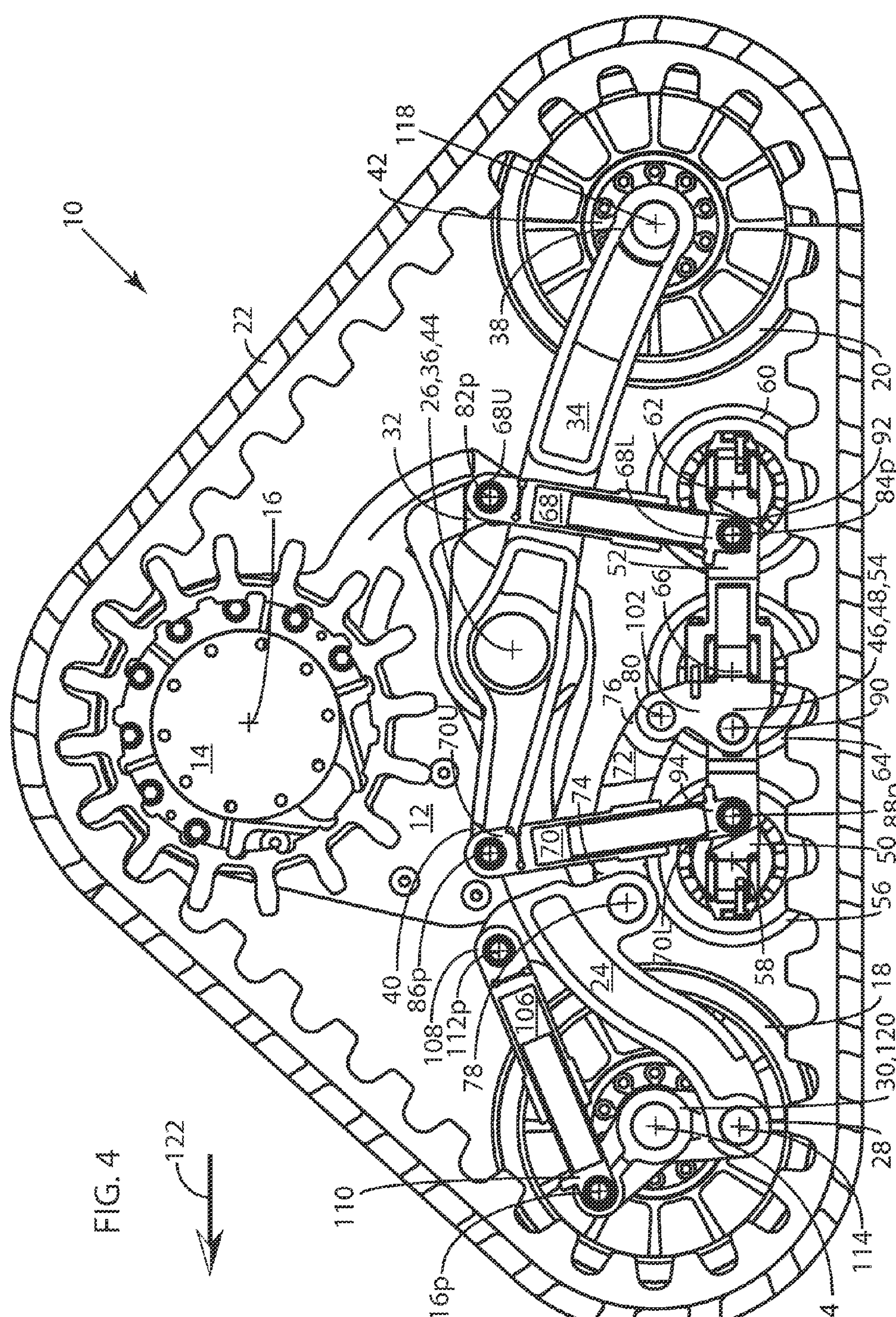


FIG. 3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82p
32
68U
68
34
60
62
68L
20
92
84p
52
66
102
46,48,54
80
76
72
74
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64
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88p
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70L
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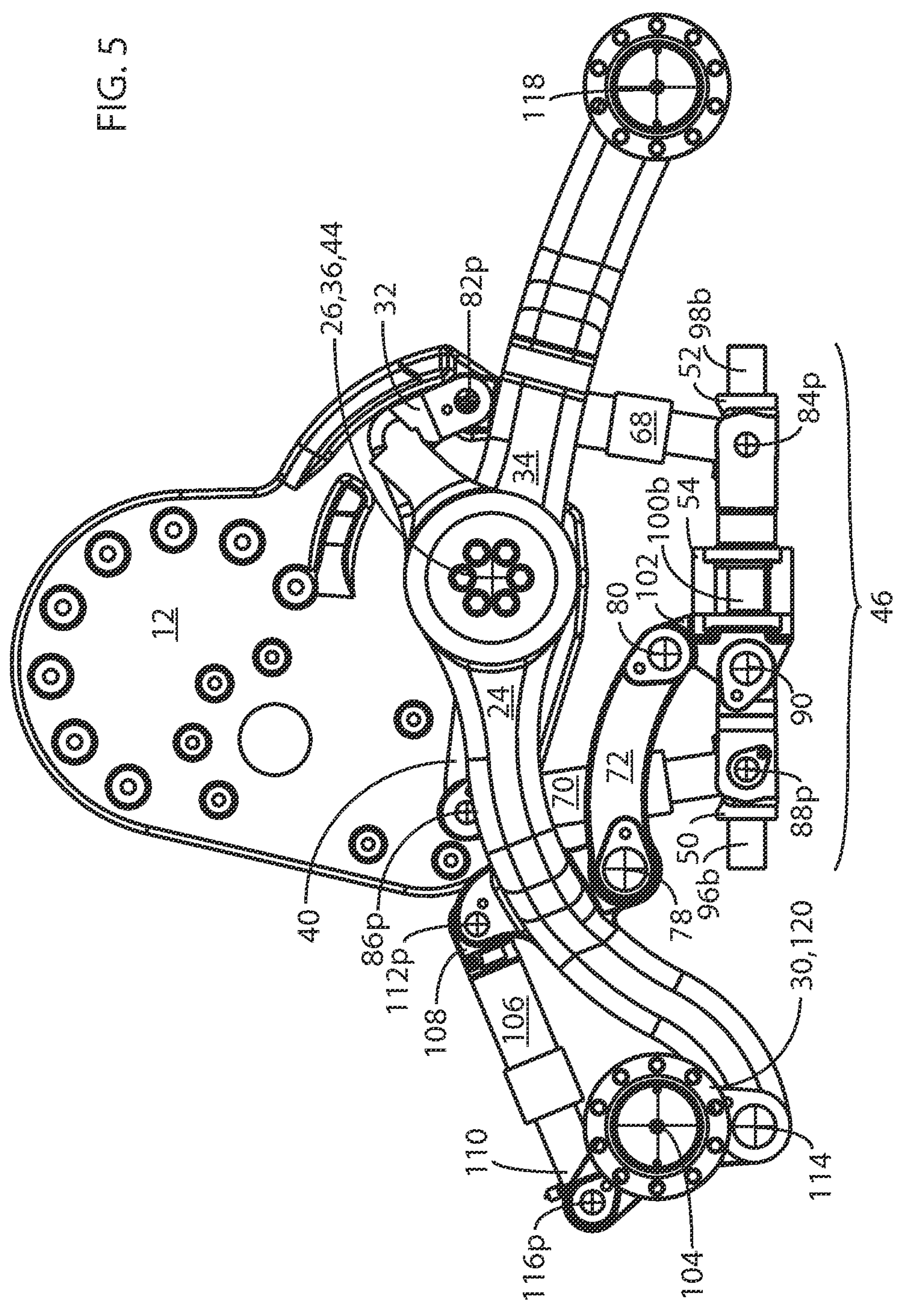
114
104

FIG. 4

FIG. 5



118
26,36,44
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84p
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100b
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88p
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96b
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112p
108
106
30,120
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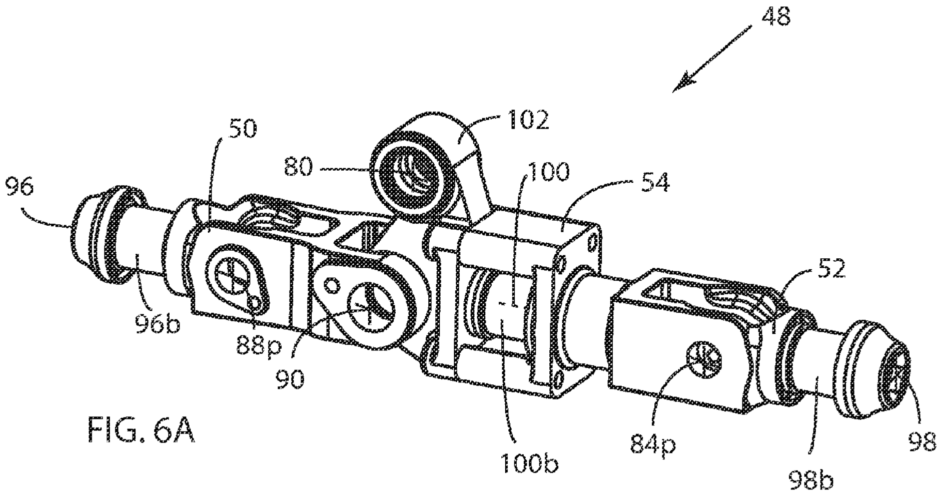
116p
104
114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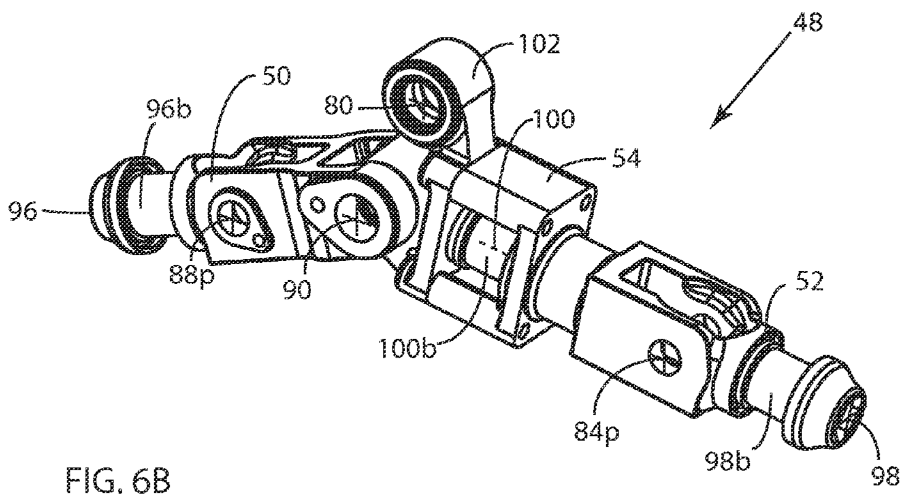
84p
98
98b

FIG. 6A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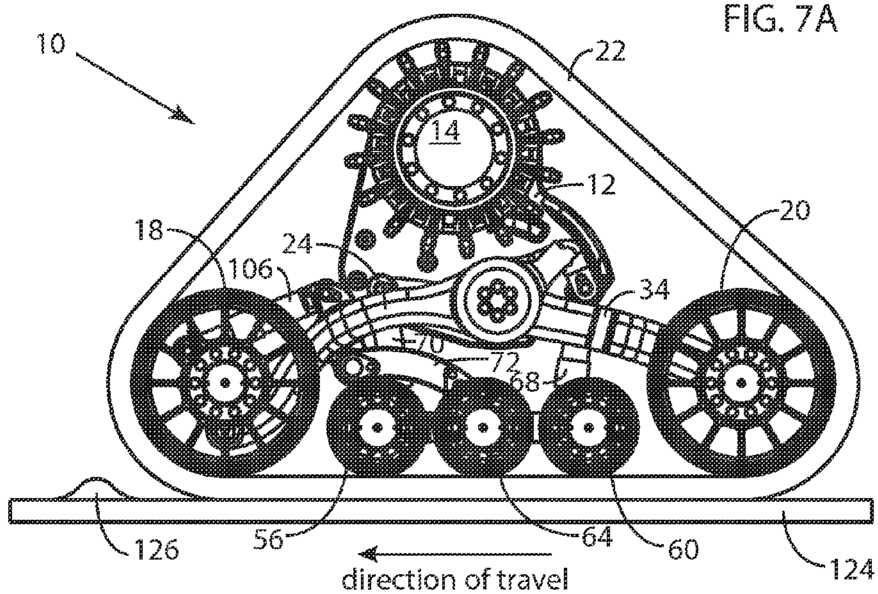
88p
90
52
100b
84p
98b
98

FIG. 6B

FIG. 7A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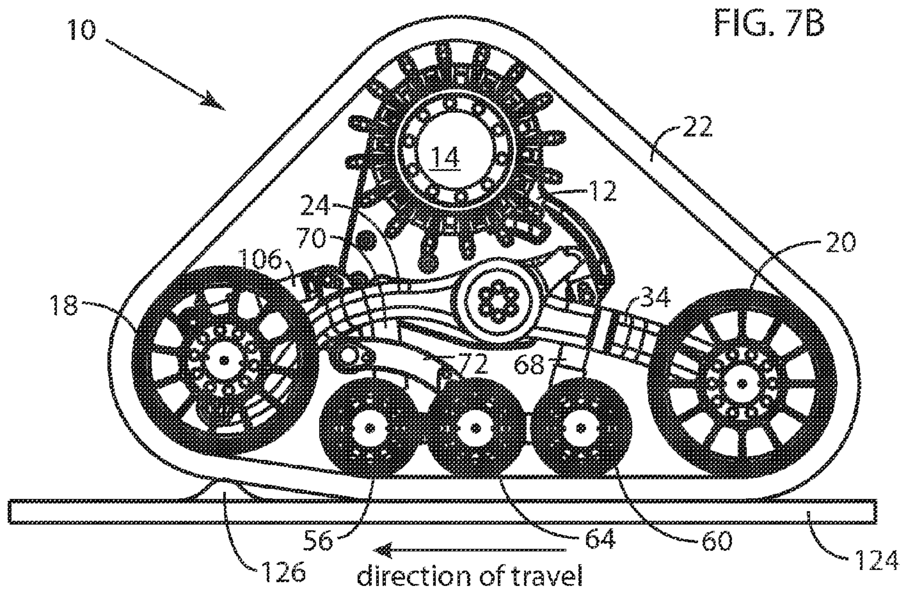
72
68
126
56
64
60
124
direction of travel

FIG. 7B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106
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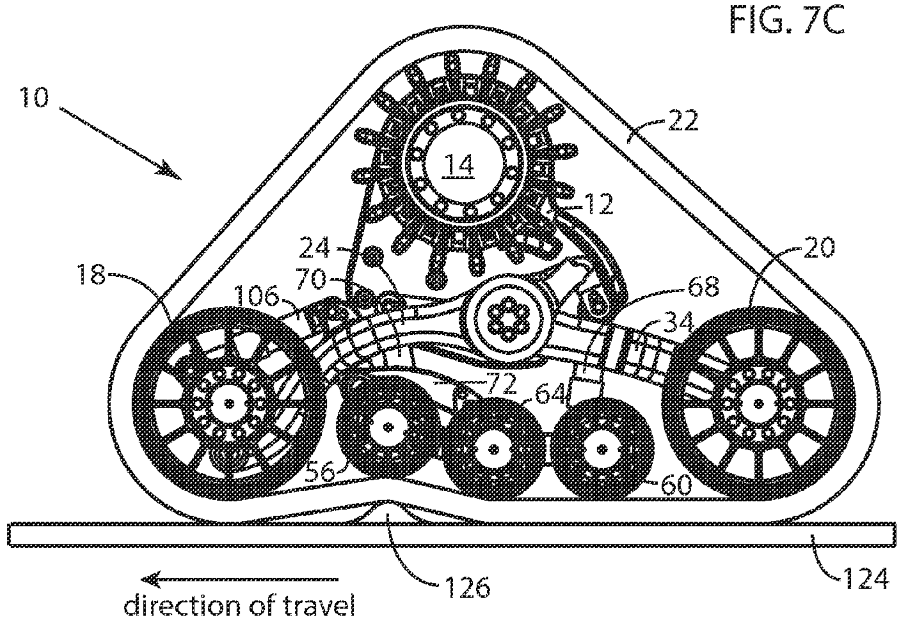
72
68
56
64
60
126
124
direction of travel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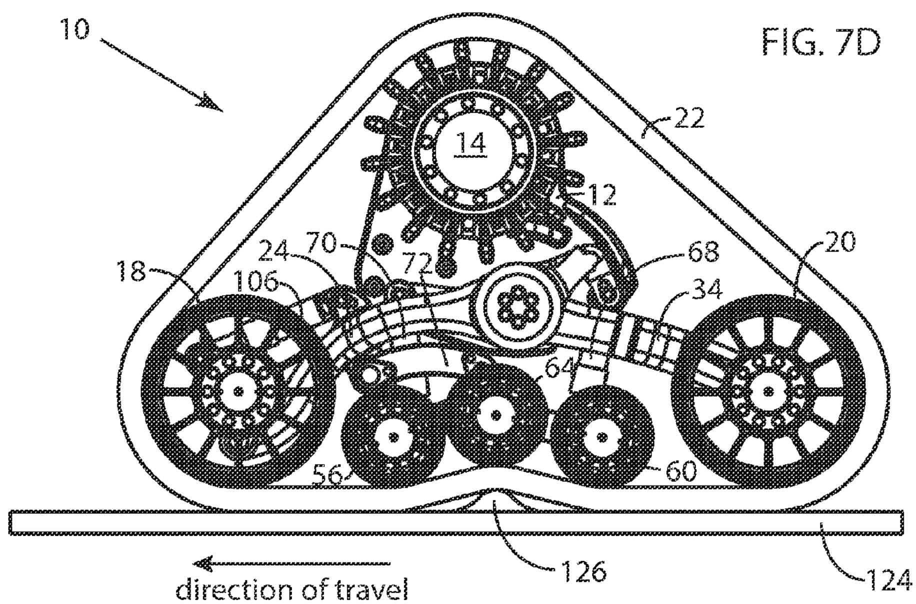
70
18
106
68
20
34
72
64
56
60
126
124
direction of travel

FIG. 7C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22
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24
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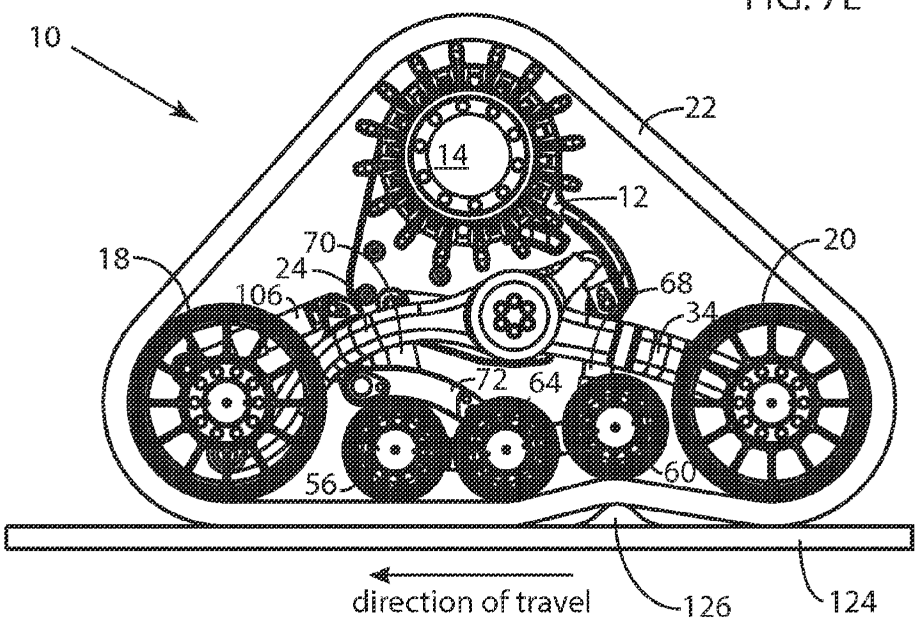
20
18
106
34
64
56
60
126
124
direction of travel

FIG. 7D

FIG. 7E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106
20
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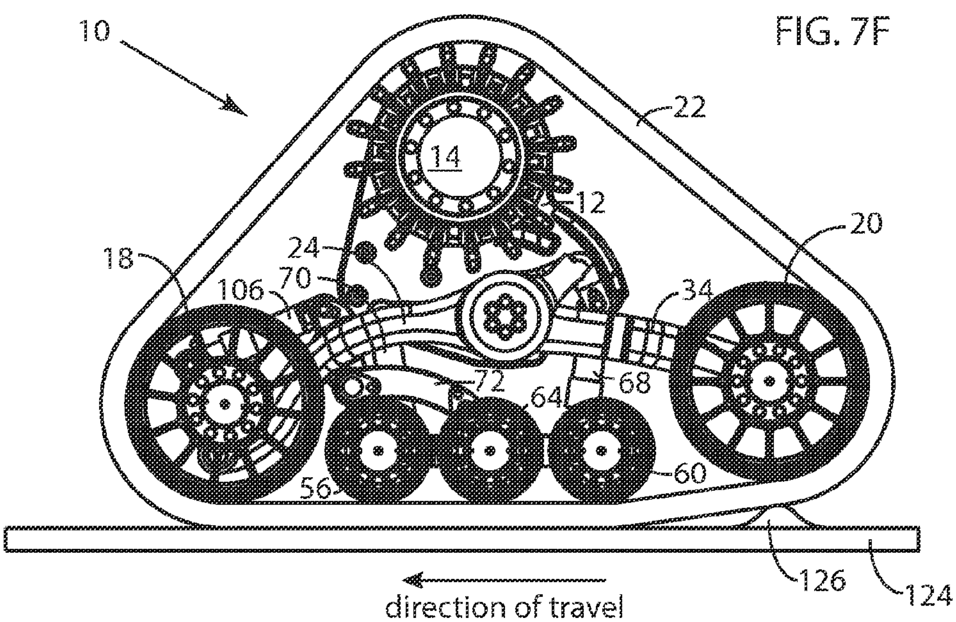
34
72
64
56
60
direction of travel
126
124

FIG. 7F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22
14
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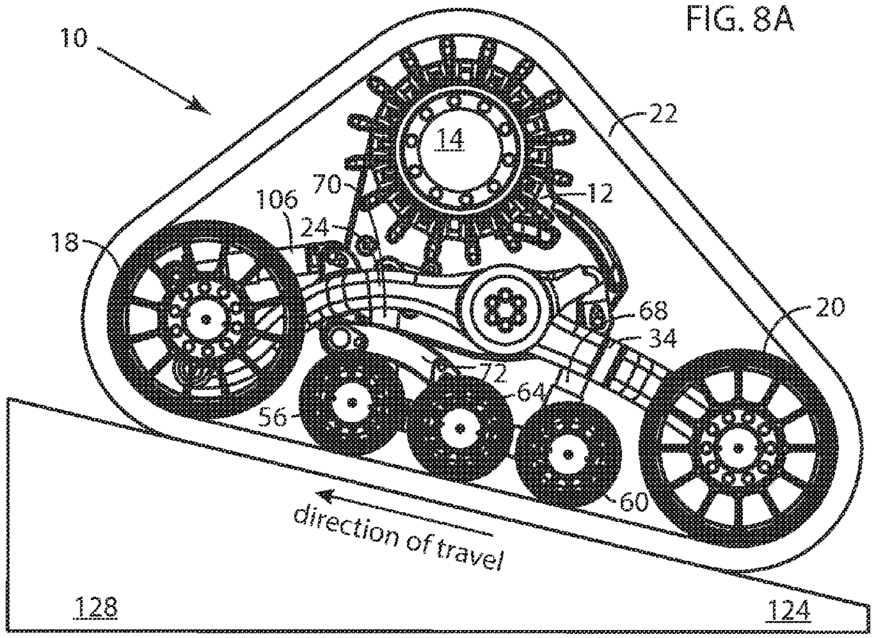
24
70
18
106
20
34
72
64
68
56
60
126
124
direction of travel

FIG. 8A


10
22
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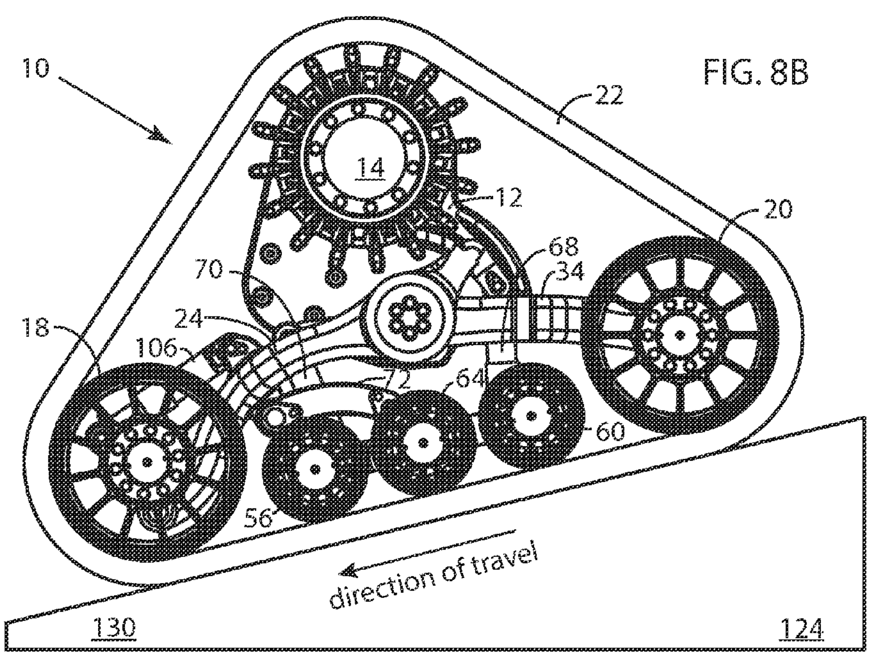
70
12
106
24
18
68
20
34
72
64
56
60
direction of travel
128
124

FIG. 8B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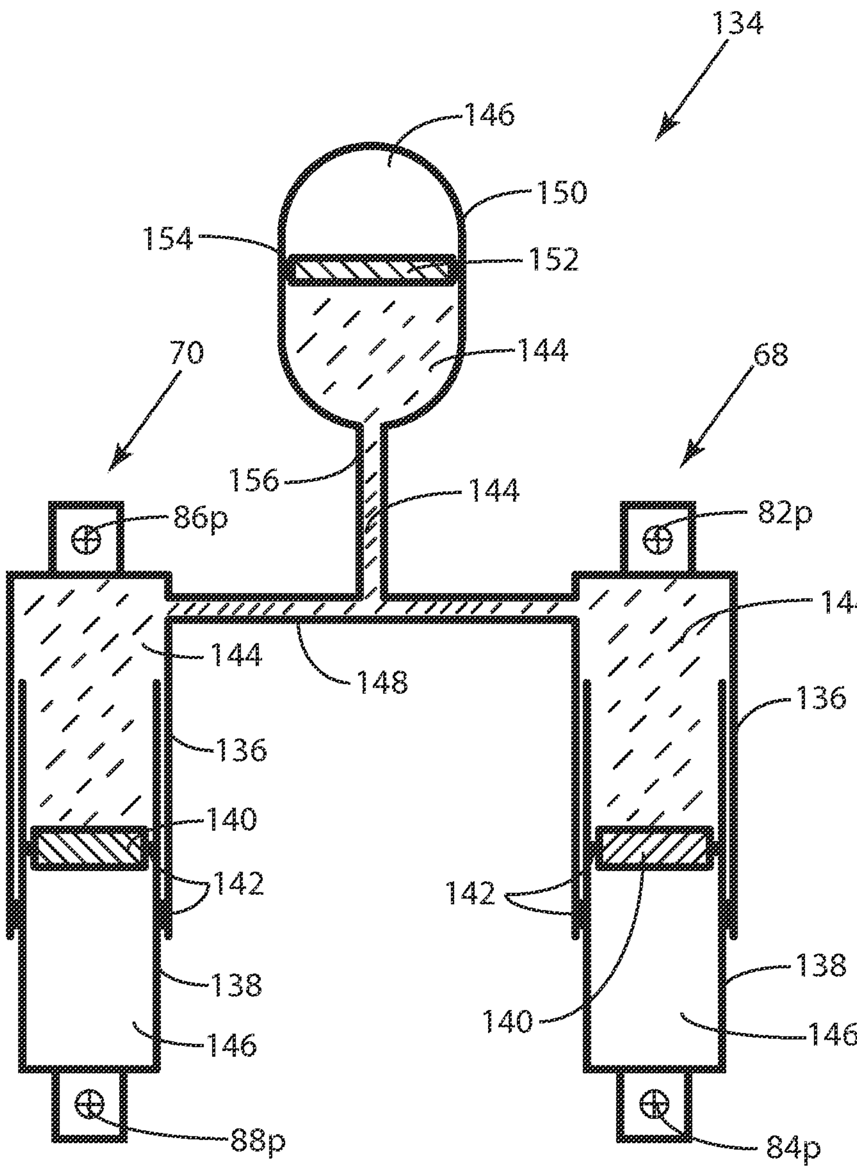
22
14
12
20
68
70
34
24
18
106
72
64
60
56
direction of travel
130
124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68
156
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86p
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144
148
136
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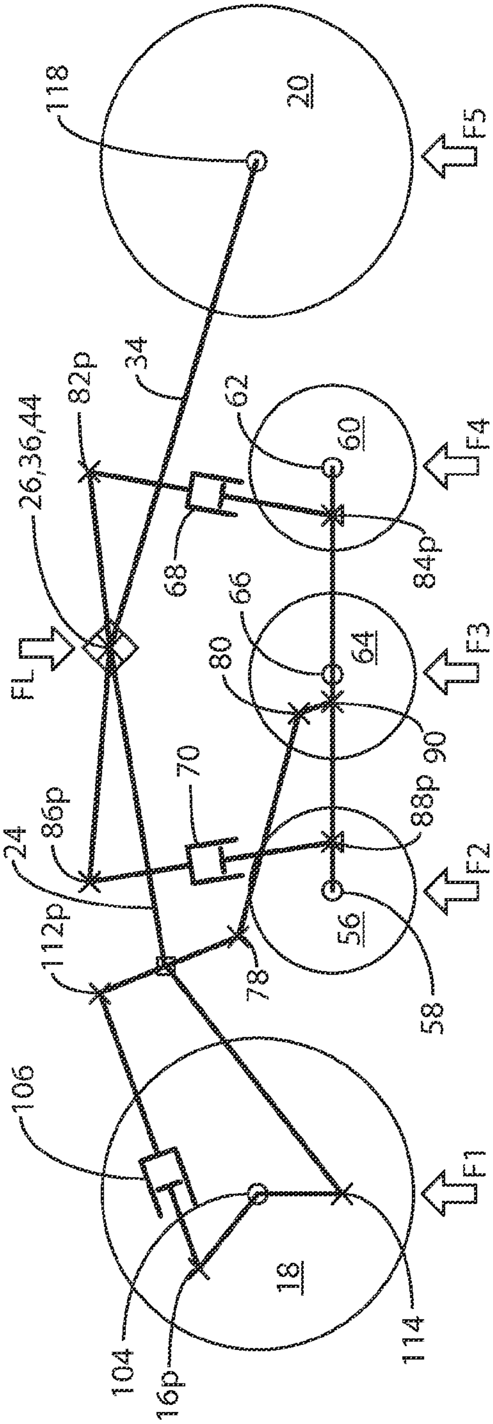
138
140
146
146
88p
84p

FIG. 9



LEGEND

○ = axis of wheel rotation

× = axis of rotation at a linkage joint

⊻ = axis of rotation at a linkage joint with rigid horizontal member

◈ = axis of rotation at point of crossing of two rigid members

□ = rigid connection at linkage intersection

FIG. 10

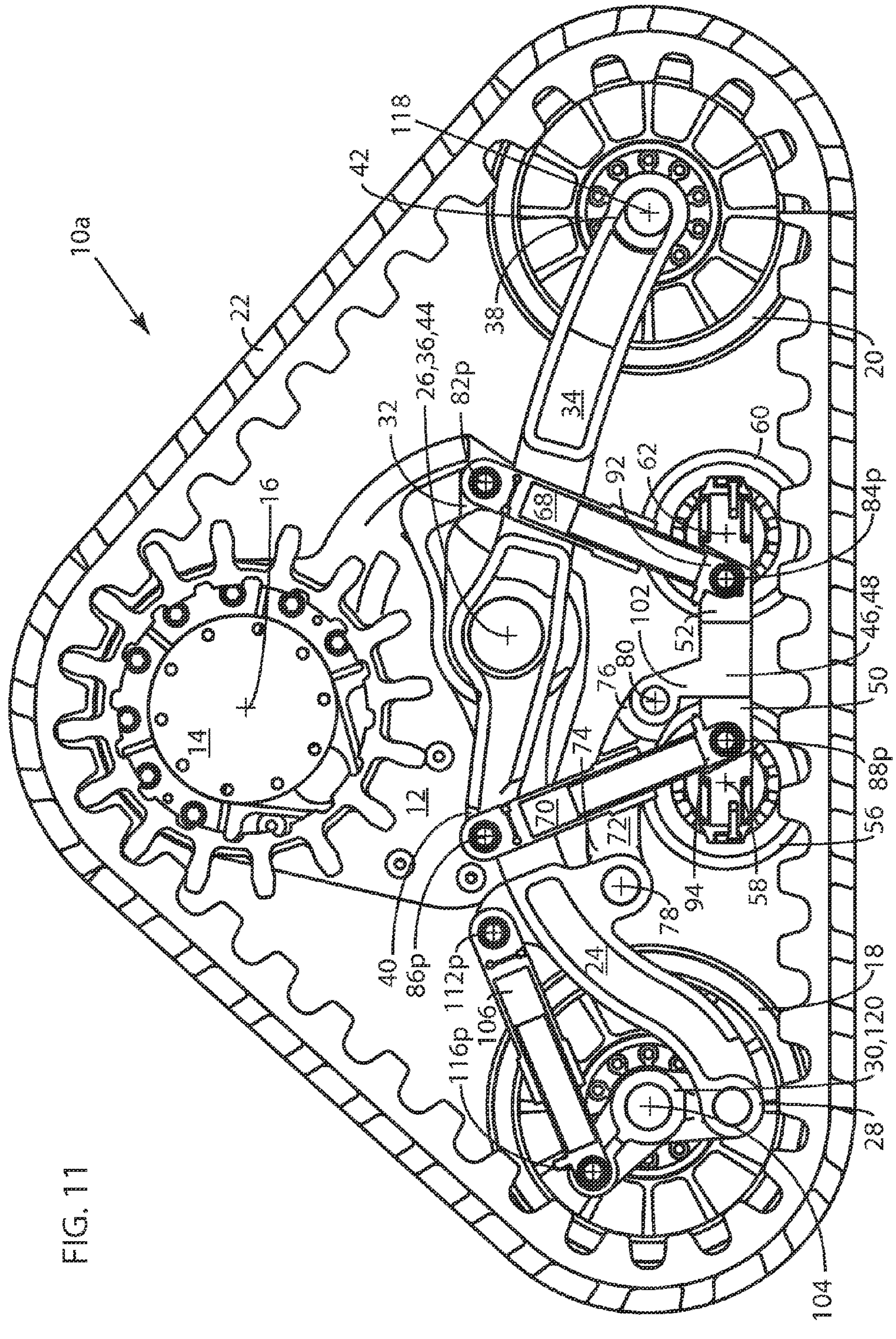
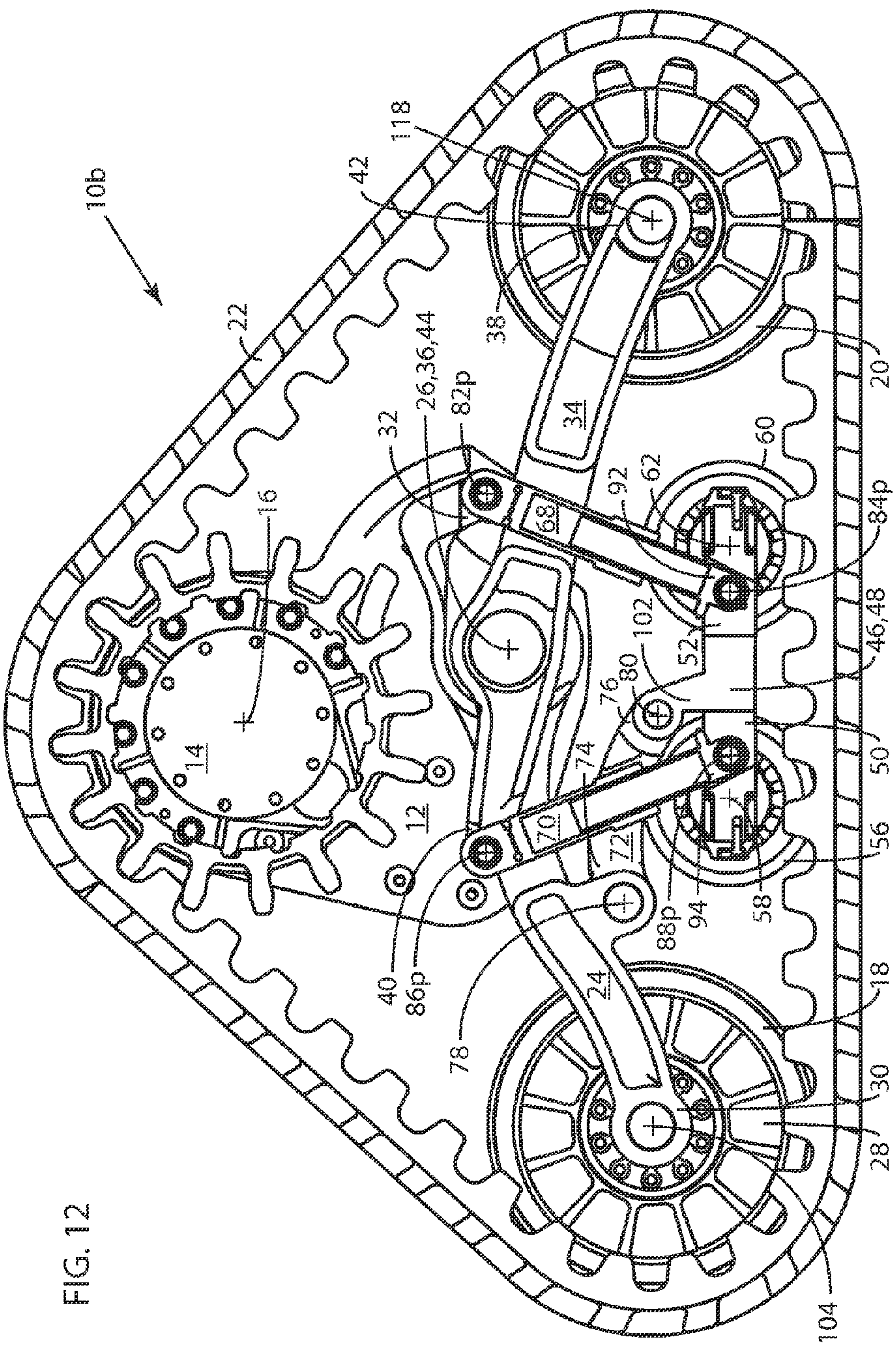

10a
22
16
14
12
118
42
38
26,36,44
82p
32
34
20
60
92
62
68
84p
102
52
46,48
80
76
50
74
88p
70
72
56
94
58
78
40
86p
112p
106
116p
24
18
30,120
28
104

FIG. 11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42
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82p
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46,48
52
80
76
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86p
78
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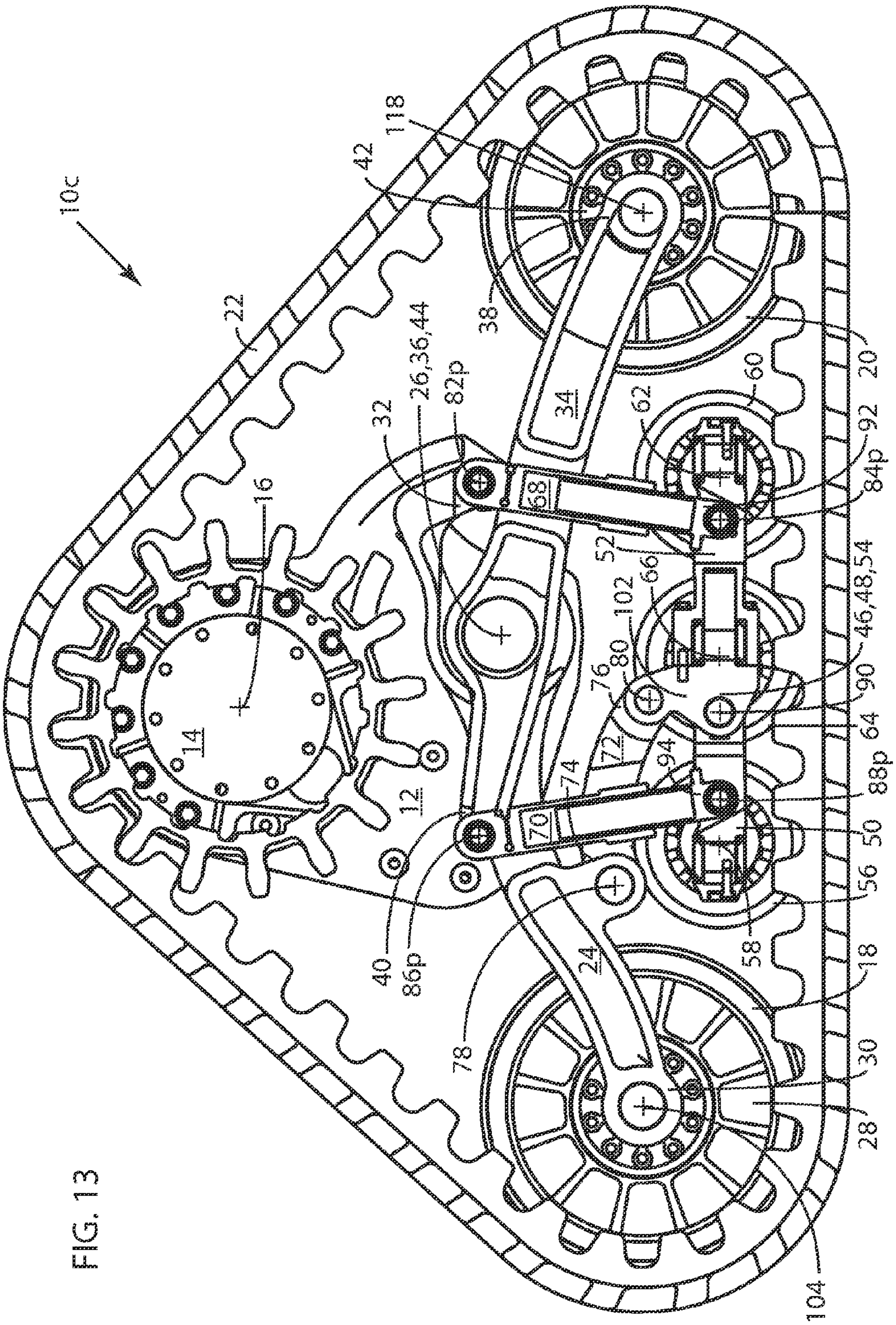
18
30
28
104

FIG. 12


10c
22
118
42
38
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34
60
62
92
84p
32
26,36,44
82p
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68
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46,48,54
14
80
76
90
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72
74
94
88p
12
70
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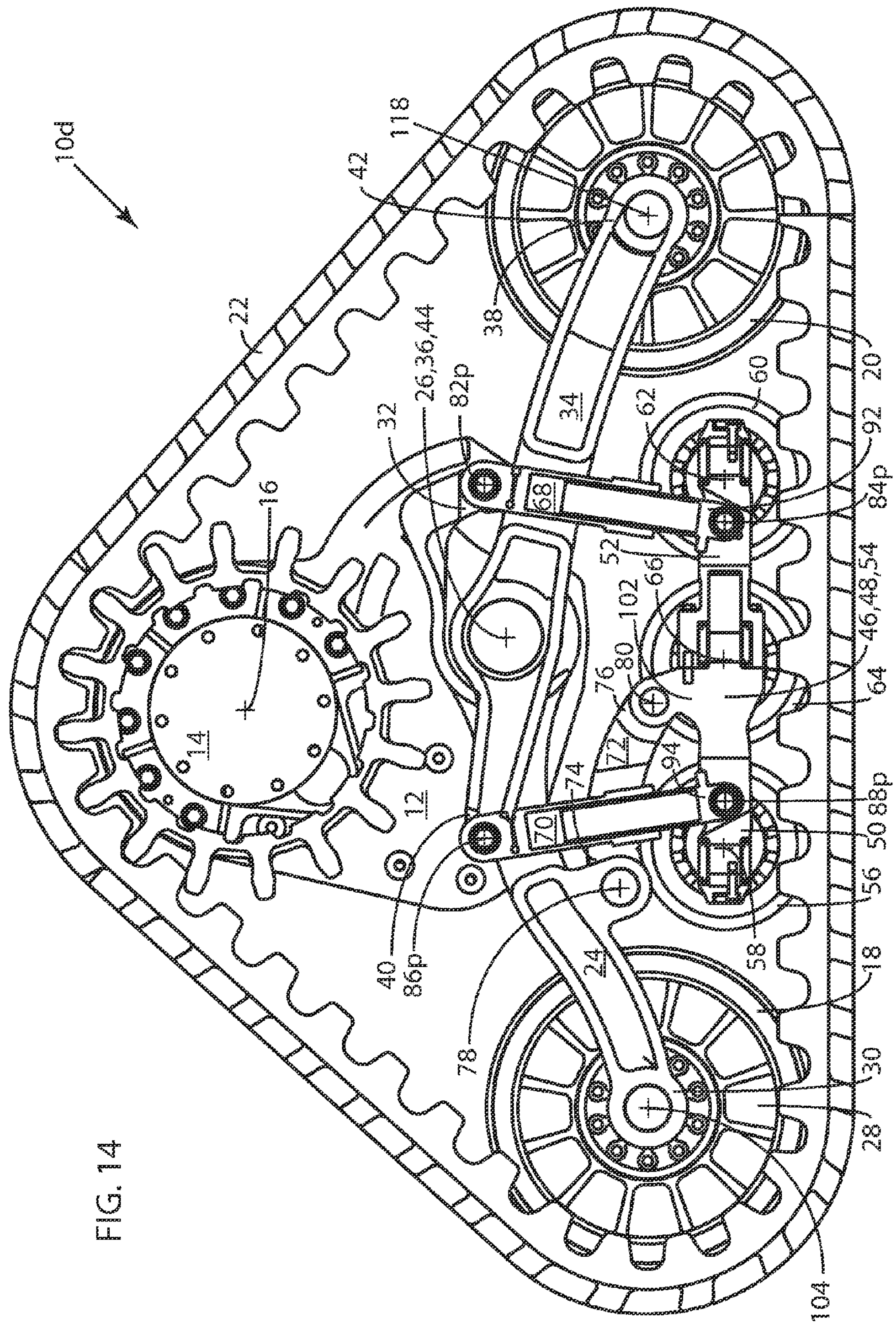
56
58
40
86p
24
18
78
30
28
104

FIG. 13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46,48,54
102
14
80
76
64
72
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74
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88p
50
70
56
58
40
86p
78
24
18
30
28
104

FIG. 14

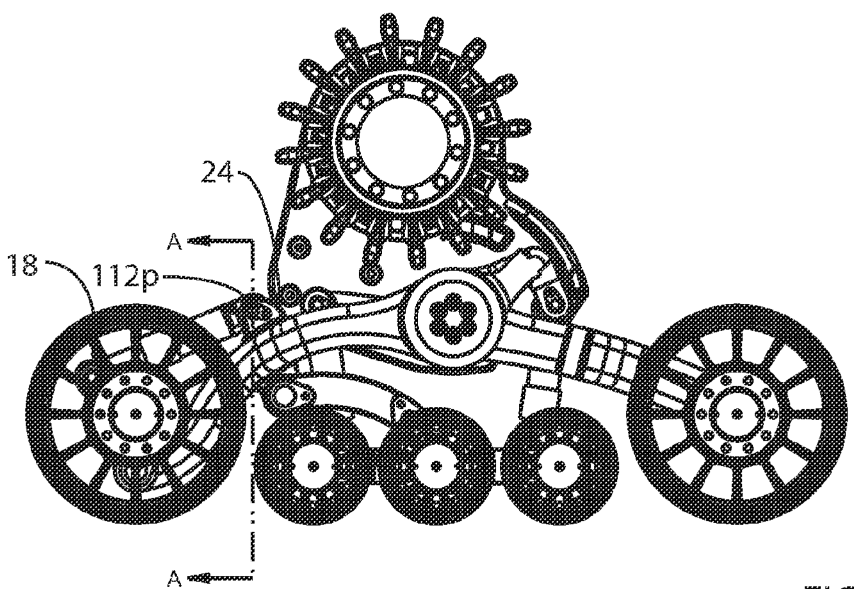


FIG. 15A

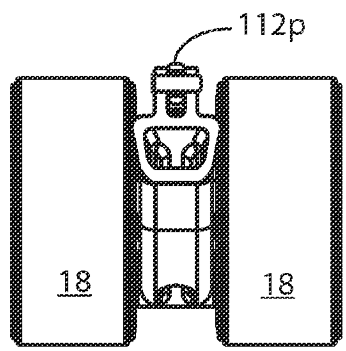


FIG. 15B

SECTION A-A

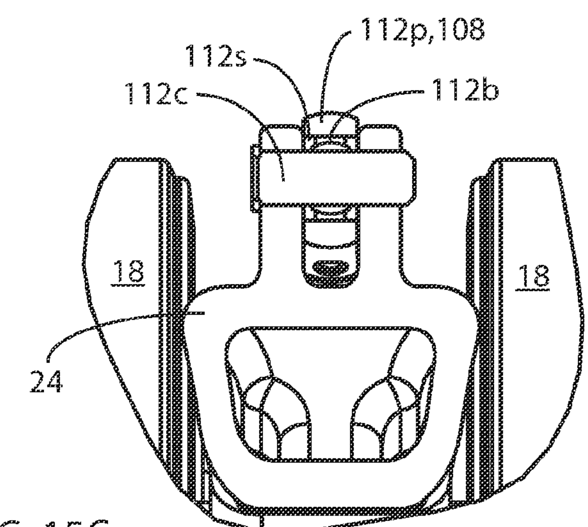


FIG. 15C

FIG. 16 - Reference Number Listing

#	Description
10	track-module apparatus
10a	first alternative embodiment of track-module apparatus
10b	second alternative embodiment of track-module apparatus
10c	third alternative embodiment of track-module apparatus
10d	fourth alternative embodiment of track-module apparatus
11	connection to vehicle
12	module frame
14	drive wheel
14g	drive gearbox
14p	drive power input shaft
16	drive wheel axis
18	leading idler wheel
20	trailing idler wheel
22	endless polymeric track
24	leading suspension arm
26	leading arm axis
28	leading-arm distal end
30	leading-idler assembly
32	rearward suspension end
34	trailing suspension arm
36	trailing arm axis
38	trailing-arm distal end
40	forward suspension end
42	trailing-idler assembly
44	suspension-arm axis
46	bogie assembly
48	bogie mount
50	bogie-mount forward portion
52	bogie-mount rearward portion
54	bogie-mount middle portion
56	leading bogie wheel
58	leading bogie axis
60	trailing bogie wheel
62	trailing bogie axis
64	middle bogie wheel
66	middle bogie axis
68	leading suspension element
68U	upper end of element 68
68L	lower end of element 68
70	trailing suspension element
70U	upper end of element 70
70L	lower end of element 70
72	bogie-assembly arm
74	bogie-assembly arm distal end
76	bogie-assembly arm proximal end
78	first bogie-assembly axis
"	third suspension joint
80	second bogie-assembly axis
82p	leading suspension-element pivot
"	first suspension joint
84p	first bogie-assembly pivot
86p	trailing suspension-element pivot
"	second suspension joint
88p	second bogie-assembly pivot
90	third bogie-assembly axis
92	rearward bogie-mount connection
94	forward bogie-mount connection
96	leading bogie roll axis
96a	leading bogie axle assembly
96b	leading bogie roll axis bearing
98	trailing bogie roll axis
98a	trailing bogie axle assembly
98b	trailing bogie roll axis bearing
100	middle bogie roll axis
100a	middle bogie axle assembly
100b	middle bogie roll axis bearing
102	bogie-mount arm
104	leading-idler axis
106	tensioning element
108	tensioning-element first end
110	tensioning-element second end
112p	proximal tensioning pivot
112b	spherical bearing ball of pivot 112p
112c	connector of pivot 112p
112s	spherical bearing socket of pivot 112p
114	idler offset axis
116p	distal tensioning pivot
118	trailing-idler axis
120	idler linkage
122	direction-of-travel arrow
124	ground
126	bump on ground
128	uphill portion of ground
130	downhill portion of ground
132	pivot connecting
134	hydraulic circuit
136	hydraulic cylinder
138	gas-filled cylinder
140	piston
142	seal
144	hydraulic fluid
146	gas
148	hydraulic conduit
150	external accumulator
152	accumulator piston
154	accumulator seal
156	accumulator conduit
200	fifth alternative module embodiment
202	unitary leading and trailing idler arms
FL	supported load
F1	resultant leading idler wheel load
F2	resultant leading bogie wheel load
F3	resultant middle bogie wheel load
F4	resultant trailing bogie wheel load
F5	resultant trailing idler wheel load

FIG. 17A: Exemplary Dimensions

Linkage	Inches
H 44:104	38
H 44:56	16.75
H 44:66	-2
H 44:62	12.75
H 44:118	34
H 44:86	16.25
H 44:88	13.25
H 44:82	12.25
H 44:84	9.25
H 44:90	6.25
H 44:78	20.2
H 44:80	7.25
H 44:112	24
H 44:116	43.25
H 44:114	38
V 44:104	11.46
V 44:56	17.58
V 44:66	17.58
V 44:62	17.58
V 44:118	11.46
V 44:86	1.7
V 44:88	17.58
V 44:82	1.7
V 44:84	17.58
V 44:90	17.58
V 44:78	9.25
V 44:80	13.38
V 44:112	1
V 44:116	7
V 44:114	18.21
D 18,20	26
D 56,60,64	13.75
V 44:16	21.2
H 44:16	6
D 12	30.6

FIG. 17B: Exemplary Load Distributions

Vehicle weight (low)	**Loads (lb)**	**Load distribution**	
1/2 axle weight	16,500	F1	11.32%
belt tension	-	F2	23.93%
pull	-	F3	23.93%
braking	-	F4	23.93%
		F5	16.88%

Vehicle weight (high)	**Loads (lb)**	**Load distribution**	
1/2 axle weight	55,000	F1	11.32%
belt tension	-	F2	23.93%
pull	-	F3	23.93%
braking	-	F4	23.93%
		F5	16.88%

Belt tension, nominal pull	**Loads (lb)**	**Load distribution**	
1/2 axle weight	16,500	F1	4.26%
belt tension	6,000	F2	28.03%
pull	4,600	F3	28.03%
braking	-	F4	28.03%
		F5	11.66%

Belt tension, high pull, high weight	**Loads (lb)**	**Load distribution**	
1/2 axle weight	55,000	F1	9.68%
belt tension	6,000	F2	26.18%
pull	17,000	F3	26.18%
braking	-	F4	26.18%
		F5	11.78%

Emergency braking, low weight	**Loads (lb)**	**Load distribution**	
1/2 axle weight	16,500	F1	0.00%
belt tension	-	F2	26.99%
pull	-	F3	26.99%
braking	29,000	F4	26.99%
		F5	19.03%

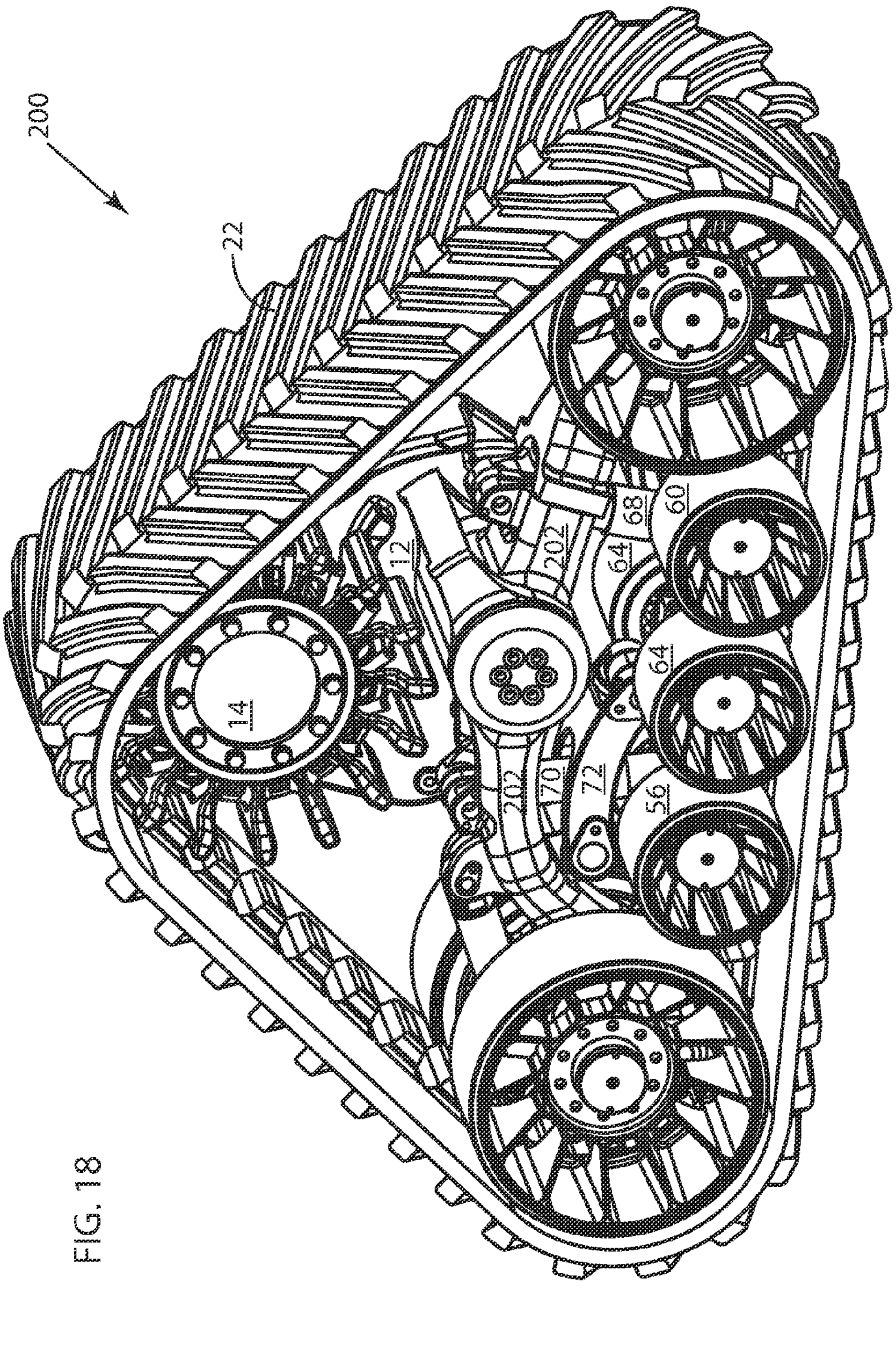
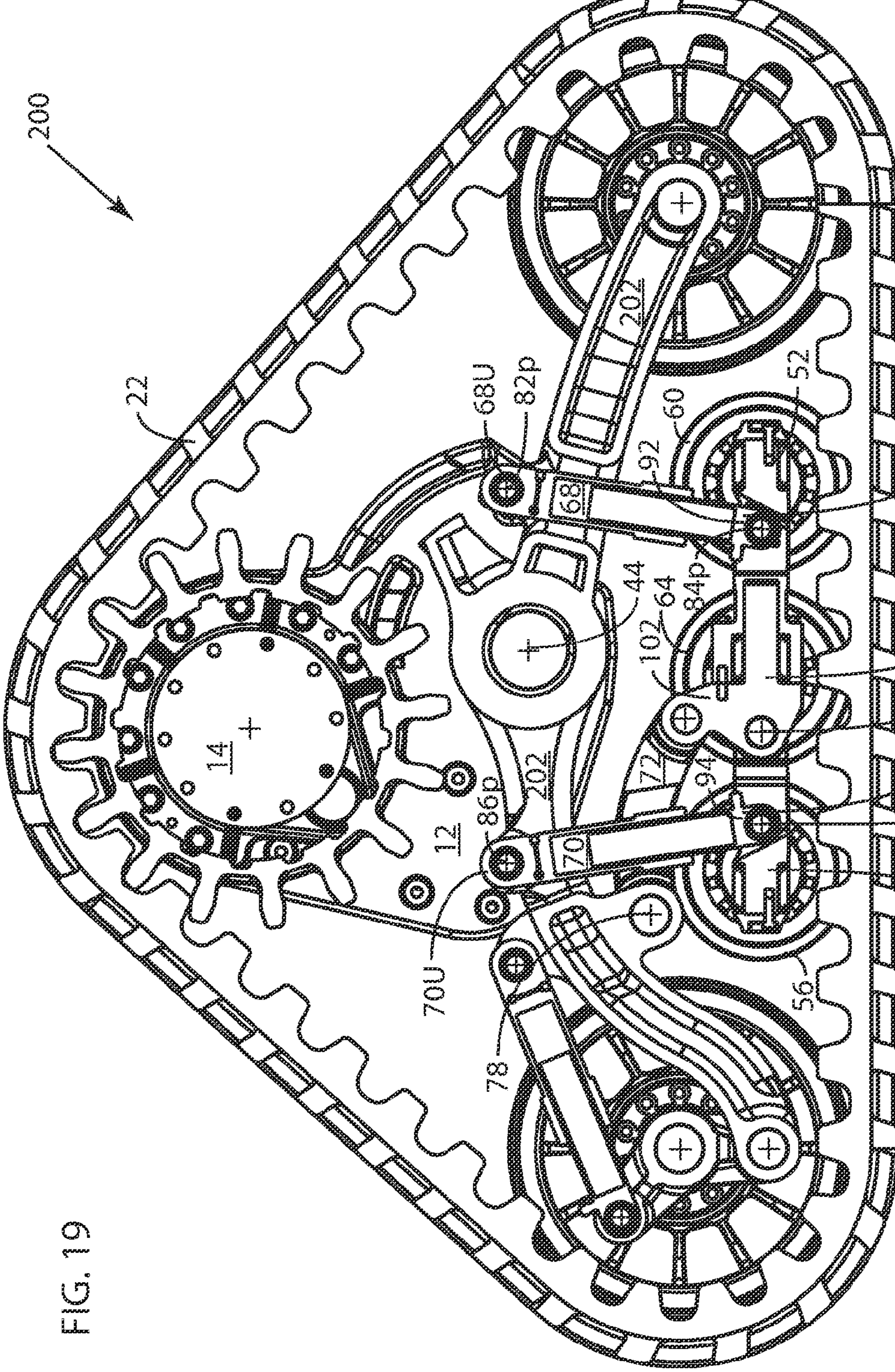


FIG. 18


200
22
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202
68U
82p
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92
60
52
68L
84p
64
102
46,48,54
90
70L
72
94
88p
86p
70
50
70U
56
78

FIG. 19

TRACK-MODULE BOGIE-SUSPENSION SYSTEM

RELATED APPLICATIONS

This application is a continuation-in-part of application Ser. No. 14/625,229 filed on Feb. 18, 2015, the contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

The invention relates generally to the field of vehicle track-module systems of the type typically for use in place of vehicle wheels and, more particularly, to track modules having leading and trailing wheels and at least one load-supporting bogie wheel between the leading and trailing wheels, all of which are engaged by an endless track extending around the wheels to drive a vehicle along the ground.

BACKGROUND OF THE INVENTION

Agricultural vehicles such as tractors, combines and the like are commonly used in agricultural fields for a variety of jobs, and construction vehicles and other large work vehicles are used for many different jobs on a variety of ground surfaces. Typically, these vehicles have large wheels with tires on which the vehicles are supported on the ground. However, for improved traction, vehicle track-module systems (or "track modules" or track-module apparatus") are used in place of wheels with tires, and such track-module systems provide a much larger ground-surface engagement area supporting vehicle weight and tends to prevent vehicles from becoming bogged down in mud or other soft ground surfaces.

Among the challenges encountered in the use of vehicle track-module apparatus is the need to distribute the load supported by the track module among the various wheels. These loads are both static and dynamic and may change during operation of the vehicle. Loads change as the vehicle encounters uneven ground, as the vehicle turns and as the slope of the ground being traversed changes. Ideally, all wheels remain in contact with the ground through the endless belt and share a portion of the load at all times.

One track-module unit which is intended to distribute load relatively evenly is disclosed in U.S. Pat. No. 7,628,235 (Satzler et al.) owned by CLAAS Industrietechnik GmbH of Paderhorn, Germany. A vehicle track roller unit is disclosed which has at least one pivotable subframe and at least one further pivotable subframe, and each of the subframes rotatably accommodates at least one land wheel. At least one subframe is pivotably mounted on the vehicle, and the at least one further subframe is pivotably mounted on the at least one pivotable subframe.

Another vehicle track-module unit is disclosed in United States Published Patent Application No. 2013/0154345 (Schultz et al.) owned by CLAAS Selbstfahrende Erntemaschinen GmbH of Harsewinkel, Germany. A vehicle track unit is disclosed which has a plurality of supporting rollers arranged one behind the other in the direction of travel of the vehicle and around which a belt is wrapped. The rollers are adjusted by way of at least one actuator between a first configuration, in which all supporting rollers are loaded, and a second configuration, in which at least one outer roller of the supporting rollers is relieved. An energy source delivers drive energy required to adjust the configuration. An energy accumulator is charged by the drive energy source and

connected to the actuator in order to provide the actuator with the drive energy required to adjust the configuration.

CLAAS also has its Lexion Terra Trac product line which includes configurations which are intended to address some of these challenges. However, none of these prior art systems includes all of the elements of the present invention and meets the needs as outlined above.

OBJECTS OF THE INVENTION

It is an object of this invention to provide track-module bogie-suspension apparatus which has high load-supporting capability while maintaining lower contact forces on the ground by providing lower loading per axle from more even load distribution.

Another object of this inventive track-module bogie-suspension apparatus is to minimize the unsprung mass of track-module apparatus.

Another object of the inventive vehicle track-module bogie-suspension apparatus is to provide track-module bogie-suspension apparatus which shares load changes between axles.

Yet another object of the inventive vehicle track-module bogie-suspension apparatus is to provide track-module apparatus in which the load distribution on the wheels is independent of vertical load.

Still another object of the inventive vehicle track-module bogie-suspension apparatus is to provide track-module apparatus which has independent roll-mode movement for all bogie axes.

An additional object of this invention is to provide track-module bogie-suspension apparatus which includes an articulating bogie assembly and which includes independent accommodation of bogie roll motion.

These and other objects of the invention will be apparent from the following descriptions and from the drawings.

BRIEF SUMMARY OF THE INVENTION

This invention is a track-module bogie-suspension apparatus for attachment to a track module which includes a frame, a drive wheel and an endless track. The inventive bogie-suspension apparatus comprises: (1) a bogie assembly having a bogie mount, at least one rotatable ground-engaging bogie wheel thereon, and forward and rearward bogie-mount connections; (2) first and second load- and ground-responsive suspension joints spaced from one another in a forward/rearward direction; and (3) leading and trailing suspension elements each having an upper end and a lower end, the upper ends of the leading and trailing suspension elements rotatably attached to the first and second suspension joints, respectively, and the lower ends thereof rotatably attached to the rearward and forward bogie-mount connections, respectively.

The term "suspension elements" as used herein refers to components in the suspension system which provide spring force and/or damping in the system.

The term "ground-engaging" as used herein with respect to a wheel means that the wheel bears on the ground through the endless track that engages the wheel under normal operating conditions.

The term "bogie wheel(s)" as used herein refers to one or more wheels providing support for a vehicle in a middle ground-engaging region of a track module, with other ground-engaging support being provided rearward and/or forward of the bogie wheels(s).

The term "therebetween" when referring to the position of ground-engaging bogie wheels means that the bogie wheels are positioned behind the leading ground-engaging wheel(s) and ahead of the trailing ground-engaging wheel(s) along the direction of travel. The term "idler" as used herein refers to wheel which is not a driven wheel but turn only by virtue of its engagement with the endless track.

The term "load- and ground-responsive" as used herein with respect to suspension joints means that the above-ground positions of such joints are variable, including with respect to the frame, and depend on the contour of the ground under the track and on the total loading on the track module, however caused.

The term "interdependent" as used herein in the describing the movements of a set of load- and ground-responsive suspension joints refers to the fact that the movement in one such joint causes movements in all joints in the set. This interdependence may be brought about by having rigid structures which connect such interdependent suspension joints. The movements of such interdependent joints are not necessarily in the same direction nor of the same magnitude; these relationships depend on the structural configurations connecting such suspension joints.

Certain preferred embodiments of the inventive bogie-suspension apparatus of claim **1** further includes a third load- and ground-responsive suspension joint, and the bogie assembly further includes a bogie-assembly arm which is rotatably attached (a) at a bogie-assembly arm distal end to the third suspension joint and (b) at a bogie-assembly arm proximal end to the bogie mount. In some of these embodiments, the rotatable attachments of the leading and trailing suspension elements at the first and second suspension joints, respectively, are configured to permit rotation having at least two degrees-of-freedom, and the rearward and forward rotatable bogie-mount connections are configured to permit rotation having at least two degrees-of-freedom.

In some preferred embodiments of the bogie-suspension apparatus, the at least one bogie wheel includes at least one leading bogie wheel and at least one trailing bogie wheel, and the bogie mount includes (a) a bogie-mount forward portion which has the at least one leading bogie wheel rotatably attached thereto at a leading bogie axis, the bogie-mount forward portion including the forward bogie-mount connection, and (b) a bogie-mount rearward portion which has the at least one trailing bogie wheel rotatably attached thereto at a trailing bogie axis, the bogie-mount rearward portion including the rearward bogie-mount connection.

Certain preferred embodiments include at least two leading bogie wheels and at least two trailing bogie wheels, the leading bogie axis rotates on a leading bogie roll axis perpendicular thereto, and the trailing bogie axis rotates on a trailing bogie roll axis perpendicular thereto.

In some other embodiments, the bogie-mount forward and rearward portions are rotatably attached at a third bogie-assembly axis.

In some preferred embodiments, the bogie mount further includes a bogie-mount middle portion which has at least one middle bogie wheel attached thereto at a middle bogie axis. Some of these embodiments include at least two leading bogie wheels, at least two trailing bogie wheels, and at least two middle bogie wheels. In these embodiments, (a) the leading bogie axis rotates on a leading bogie roll axis perpendicular thereto, (b) the middle bogie axis rotates on a middle bogie roll axis perpendicular thereto, and (c) the trailing bogie axis rotates on a trailing bogie roll axis perpendicular thereto. Further, in some of these embodiments, the bogie-mount forward and middle portions are rotatably attached at a third bogie-assembly axis.

In some highly-preferred embodiments of the inventive bogie-suspension apparatus, the leading and trailing suspension elements each include gas-filled components to provide spring force. In some of these embodiments, the leading and trailing suspension elements each further include hydraulic components, and in some of these embodiments the leading and trailing suspension elements are on a common hydraulic circuit. Also, some of these embodiments include an external accumulator hydraulically which is connected to the common hydraulic circuit.

In some embodiments which have plural bogie wheels, the bogie wheels have diameters which are substantially the same as each other.

In some highly-preferred embodiments, the first and second load- and ground-responsive suspension joints are independently responsive to load and ground variations. In some other embodiments, the movements of the first and second load- and ground-responsive suspension joints are interdependent.

Some highly-preferred embodiments also include a third load- and ground-responsive suspension joint, and the bogie assembly further includes a bogie-assembly arm rotatably attached (a) at a bogie-assembly arm distal end to the third suspension joint and (b) at a bogie-assembly arm proximal end to the bogie mount. In such embodiments, the movements of the suspension joints are interdependent.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a perspective drawing of an embodiment of the vehicle track-module apparatus of this invention.

FIG. **1**B is a perspective drawing of the embodiment of FIG. **1**A as viewed from the side opposite that shown in FIG. **1**A.

FIG. **2** is a perspective drawing of portions of the embodiment of the vehicle track-module apparatus of FIGS. **1**A and **1**B, illustrating the suspension linkage components without the drive wheel, endless polymeric track, wheels, frame and suspension elements.

FIG. **3** is an exploded perspective drawing of the embodiment of FIGS. **1**A and **1**B.

FIG. **4** is a side-elevation drawing of the embodiment of FIGS. **1**A and **1**B with the near set of idler and bogie wheels removed to show the linkages.

FIG. **5** is side-elevation drawing of portions of the embodiment of the vehicle track-module apparatus of FIGS. **1**A and **1**B, showing the suspension linkage components without the drive wheel and the endless track and wheels.

FIG. **6**A is a perspective drawing of the bogie mount portions of the bogie assembly of the vehicle track-module apparatus of FIGS. **1**A and **1**B.

FIG. **6**B is a perspective drawing of the bogie mount of FIG. **6**A showing the bogie-mount forward portion rotated with respect to the bogie-mount rearward portion around the third bogie-assembly axis.

FIGS. **7**A-**7**F are side-elevation drawings of the embodiment of FIGS. **1**A and **1**B illustrating the movement of the vehicle track-module apparatus as it traverses over a small bump along its path of travel. FIG. **7**A shows the track-module apparatus just prior to encountering the bump.

FIG. **7**B shows the track-module apparatus with its leading idler wheels over the bump.

FIG. **7**C shows the track-module apparatus with its leading bogie wheels over the bump.

FIG. **7**D shows the track-module apparatus with its middle bogie wheels over the bump.

FIG. **7**E shows the track-module apparatus with its trailing bogie wheels over the bump.

FIG. **7**F shows the track-module apparatus with its trailing idler wheels over the bump.

FIG. **8**A is a side-elevation drawing of the embodiment of FIGS. **1**A and **1**B illustrating the movement of the vehicle track-module apparatus as it traverses an uphill path.

FIG. **8**B is a side-elevation drawing of the embodiment of FIGS. **1**A and **1**B illustrating the movement of the vehicle track-module apparatus as it traverses a downhill path.

FIG. **9** is a schematic drawing of the leading and trailing suspension elements in a hydraulic circuit.

FIG. **10** is a schematic diagram of the embodiment of FIGS. **1**A and **1**B illustrating the supported load FL and the five resulting wheel loads F**1** through F**5**.

FIG. **11** is a side-elevation drawing (similar to FIG. **4**) of a first alternative embodiment of the vehicle track-module apparatus of this invention. Such embodiment is similar to the embodiment of FIG. **4** but includes only leading and trailing bogie wheels with corresponding modifications to the components used in the suspension system.

FIG. **12** is a side-elevation drawing (similar to FIG. **4**) of a second alternative embodiment of the vehicle track-module apparatus of this invention. Such embodiment is similar to the embodiment of FIG. **11** but does not include a tensioning element and the leading-idler assembly includes only the leading idler wheel.

FIG. **13** is a side-elevation drawing (similar to FIG. **4**) of a third alternative embodiment of the vehicle track-module apparatus of this invention. Such embodiment is similar to the embodiment of FIG. **4** but does not include a tensioning element and the leading-idler assembly includes only the leading idler wheel.

FIG. **14** is a side-elevation drawing (similar to FIG. **4**) of a fourth alternative embodiment of the vehicle track-module apparatus of this invention. Such embodiment is similar to the embodiment of FIG. **13** but does not include the third bogie-assembly axis.

FIG. **15**A is side-elevation drawing of portions of the embodiment of the vehicle track-module apparatus of FIG. **1** to illustrate the detail of an end of the tensioning element.

FIG. **15**B is a sectional view of FIG. **15**A.

FIG. **15**C is an enlargement of a portion of FIG. **15**B particularly showing an end of the tensioning element.

FIG. **16** is a table of reference numbers for the components and other things illustrated in FIGS. **1**A-**15**C and **17**A-**20** and for the forces represented in the drawings.

FIG. **17**A is a table of dimensions for an exemplary track-module apparatus.

FIG. **17**B is a set of five tables illustrating five different sets of loads on the exemplary apparatus of FIG. **17**A and the five resulting load distributions.

FIG. **18** is perspective drawing of a fifth alternative track-module embodiment that includes a bogie-suspension apparatus in which the movements of the first and second load- and ground-responsive suspension joints are interdependent.

FIG. **19** is a side elevation drawing of the embodiment of FIG. **18**.

DETAILED DESCRIPTIONS OF PREFERRED EMBODIMENTS

FIG. **1**A is a perspective drawing of an embodiment **10** of the vehicle track-module apparatus of this invention. (As referred to herein, an embodiment of a track-module apparatus and the track-module apparatus itself may be referred to using the same reference number. Thus, for example, "embodiment **10**" and "track-module apparatus **10**" refer to the same apparatus.) Embodiment **10** includes a module frame **12**, a drive wheel **14** which is rotatable with respect to frame **12**, the drive wheel having a drive wheel axis **16**, ground-engaging leading wheels **18** and ground-engaging trailing wheels **20** and ground-engaging bogie wheels **56**, **60** and **64**, and an endless track **22** which extends around wheels **14**, **18**, **20**, **56**, **60** and **64** and is driven by its engagement with drive wheel **14**.

FIG. **1**B is a perspective drawing of track-module apparatus **10** of FIG. **1**A as viewed from the side opposite that shown in FIG. **1**A. Referring to FIG. **1**B, track-module apparatus **10** includes a vehicle connection **11** at which track-module apparatus **10** is attached to a vehicle and a drive gearbox **14***g* which receives power from the vehicle through a drive power input shaft **14***p*.

In embodiment **10**, leading wheels **18** are leading idler wheels **18**, and trailing wheels **20** are trailing idler wheels **20**. In some embodiments of the track-module apparatus disclosed herein, it is contemplated that a leading or trailing wheel may also function as the drive wheel. Also in embodiment **10**, endless track **22** is an endless polymeric track **22**. It is contemplated that endless track **22** may be constructed of a wide variety of materials and structures including metallic components such as are presently known in some tracked vehicles. The specific properties and materials of the endless track are not central to the concepts of the track-module configuration.

Bogie wheels **56** are leading bogie wheels, bogie wheels **60** are trailing bogie wheels, and bogie wheels **64** are middle bogie wheels. Bogie wheels **56**, **60** and **64** are part of a bogie assembly **46**. Embodiment **10** also includes a leading suspension arm **24**, a trailing suspension arm **34**, a leading suspension element **68**, a trailing suspension element **70**, and a tensioning element **106**. Leading suspension element **68** includes upper end **68**U and a lower end **68**L, and trailing suspension element **70** includes an upper end **70**U and a lower end **70**L. The upper-end and lower-end nomenclature and reference number usage is specifically shown in FIGS. **4** and **18**-**19** and discussed with respect to the embodiment of FIGS. **18**-**19**.

The direction of forward travel of the track module of embodiment **10** (and other similar embodiments presented herein) is defined by leading idler wheels **18** being ahead of trailing idler wheels **20**. FIG. **4** includes an arrow **122** indicating the direction of travel applicable to all embodiments as defined by the leading and trailing components of the embodiments.

FIGS. **2** through **6**B illustrate track-module apparatus **10** and various partial assemblies thereof in several views in order to show more clearly the various aspects of track-module apparatus **10**. FIG. **2** is a perspective drawing of portions of track-module apparatus **10**, illustrating the several suspension linkage components without drive wheel **14**, track **22**, leading idler wheels **18**, trailing idler wheels **20**, leading bogie wheels **56**, trailing bogie wheels **60**, middle bogie wheels **64**, frame **12**, leading suspension element **68**, trailing suspension element **70**, and tensioning element **106**. FIG. **3** is an exploded perspective drawing of track-module apparatus **10**.

FIG. **4** is a side-elevation drawing of track-module apparatus **10** with the near (in the drawing) set of idler wheels **18** and **20** and bogie wheels **56**, **60** and **64** removed to show the various elements of embodiment **10** more clearly.

FIG. **5** is side-elevation drawing of portions of vehicle track-module apparatus **10**. Similar to FIG. **2**, FIG. **5** illustrates various components of apparatus **10** with some components not shown to increase the visibility of other components.

FIGS. **6**A and **6**B are perspective drawings of the bogie mount portions of bogie assembly **46** of vehicle track-module apparatus **10** without bogie wheels **56**, **60** and **64**. FIG. **6**A illustrates bogie mount **48** oriented as if apparatus **10** were on a flat portion of the ground. FIG. **6**B illustrates bogie mount **48** as if apparatus **10** were on uneven ground to illustrate some of the degrees-of-freedom available in the configuration of bogie mount **48** of bogie assembly **46**. Further description is presented below in this document.

The following description of track-module apparatus **10** refers to FIGS. **1**A-**6**B together. Note that in all of the drawings, a "+" symbol is used to indicate an axis of rotation. In general, as used herein, the term "axis" pertains to a pivot joint which includes the necessary bearing structure and other components to permit rotation about such axis. As an example, drive wheel axis **16** about which drive wheel **14** rotates is indicated in FIG. **4** by a "+" symbol. Portions of a bearing structure (not shown) which are needed for drive wheel **14** to rotate around axis **16** are assumed to be part of embodiment **10**. In six instances within embodiment **10**, the "+" symbol indicates a pivot point which may provide more than one degree-of-freedom of relative motion. This is indicated by (a) the name including the word "pivot" rather than "axis" and (b) the relevant reference number ending with the letter "p". These instances are **82***p*, **84***p*, **86***p*, **88***p*, **112***p* and **116***p*. As described later in this document, such higher number of degrees-of-freedom of relative motion may be provided by the use of spherical bearings. It should be understood that it is intended that in some embodiments, such "pivots" may also simply be axes configured for single degree-of-freedom rotation. The use of the term "pivot" is not intended to limit the scope of the present invention to multiple degrees-of-freedom motion at such locations within embodiments having such pivots.

Leading suspension arm **24** is rotatably attached to frame **12** at a leading arm axis **26** and extends forward to a leading-arm distal end **28** at which a leading-wheel assembly **30** is rotatably attached. In apparatus **10**, leading-wheel assembly **30** is also called leading-idler assembly **30** since in apparatus **10**, leading wheel **18** is leading idler wheel **18**. Leading suspension arm **24** extends rearwardly to a rearward suspension end **32**. In similar fashion, trailing suspension arm **34** is rotatably attached to frame **12** at a trailing arm axis **36** and extends rearward to a trailing-arm distal end **38** at which a trailing-wheel assembly **42** is attached. In apparatus **10**, trailing-wheel assembly **42** is also called trailing-idler assembly **42** since in apparatus **10**, trailing wheel **20** is trailing idler wheel **20**.

In embodiment **10**, trailing-idler assembly **42** primarily comprises trailing idler wheels **20** which are rotatably attached at a trailing-idler axis **118**. Trailing suspension arm **34** extends forwardly to a forward suspension end **40**. In embodiment **10**, leading arm axis and trailing arm axis **36** are coincident and together form suspension-arm axis **44**. Such coincidence is not intended to be limiting; other configurations of the track-module apparatus in which leading arm axis **26** and trailing arm axis **36** are not coincident are contemplated.

Suspension-arm axis **44** of embodiment **10** is shown as being rearward of and below drive wheel axis **16** as defined by direction-of-travel arrow **122** in FIG. **4**. Such relative positioning with respect to drive wheel axis **16** is not intended to be limiting; other relative positions of leading arm axis **26** and trailing arm axis **36** are contemplated for such track-module apparatus.

Bogie assembly **46** includes two leading bogie wheels **56**, two middle bogie wheels **64**, and two trailing bogie wheels **60**. Bogie assembly **46** also includes a bogie mount **48** which includes bogie-mount forward portion **50**, a bogie-mount middle portion **54**, a bogie-mount rearward portion **52**, and a bogie-mount arm **102**. Leading bogie wheels **56** are rotatable with respect to bogie-mount forward portion **50** around a leading bogie axis **58**. In addition, leading bogie axis **58** rotates through a limited range of angles about a leading bogie roll axis **96** which is perpendicular to leading bogie axis **58**.

In a similar fashion, such relative rotational movement is also provided for middle bogie wheels **64** and trailing bogie wheels **60**. Middle bogie wheels **64** are rotatable with respect to bogie-mount middle portion **54** around a middle bogie axis **66**. Middle bogie axis **66** rotates through a limited range of angles about a middle bogie roll axis **100** which is perpendicular to middle bogie axis **66**. Trailing bogie wheels **60** are rotatable with respect to bogie-mount rearward portion **52** around a trailing bogie axis **62**. Trailing bogie axis **62** rotates through a limited range of angles about a trailing bogie roll axis **98** which is perpendicular to trailing bogie axis **62**.

Bogie mount **48** also includes bearings **96***b*, **100***b* and **98***b*, configured as follows: (1) bearing **96***b* at leading bogie roll axis **96**; (2) bearing **100***b* at middle bogie roll axis **100**; and (3) bearing **98***b* at trailing bogie roll axis **98**. Bogie assembly **46** also includes a leading bogie axle assembly **96***a* to which leading bogie wheels **56** are rotatably attached, a middle bogie axle assembly **100***a* to which middle bogie wheels **64** are rotatably attached, and a trailing bogie axle assembly **98***a* to which trailing bogie wheels **60** are rotatably attached. Bearings **96***b*, **100***b* and **98***b* are configured to permit bogie axle assemblies **96***a*, **100***a* and **98***a*, respectively, to rotate on such bearings around leading bogie roll axis **96**, middle bogie roll axis **100** and trailing bogie roll axis **98**, respectively. Leading bogie roll axis **96** and trailing bogie roll axis **98** are indicated at respective ends of bogie mount **48** in FIGS. **6**A and **6**B. Also in FIGS. **6**A and **6**B, middle bogie roll axis **100** is indicated by dotted lines at middle bogie roll axis bearing **100***b* but should be understood to be located internally in the center of bearing **100***b*, parallel to such dotted lines and not on the surface of bearing **100***b*.

Bogie mount **48** of bogie assembly **46** is rotatably attached at a first bogie-assembly axis **78** to leading suspension arm **24** at a location along arm **24** between leading arm axis **26** and leading-arm distal end **28** by a bogie-assembly arm **72** at a bogie-assembly arm distal end **74**. (First bogie-assembly axis **78** is also herein referred to as third load- and ground-responsive suspension joint **78**.) Bogie-assembly arm **72** also includes a bogie-assembly arm proximal end **76** which is rotatably attached to a bogie-mount arm **102** of bogie mount **48** at a second-bogie-assembly axis **80**.

Bogie mount **48** of bogie assembly **46** is also attached to leading suspension arm **24** and trailing suspension arm **34** by suspension elements **68** and **70**. Leading suspension element **68** is rotatably attached to rearward suspension end **32** of leading suspension arm **24** at a leading suspension-element pivot **82***p* and is rotatably attached to bogie-mount rearward portion **52** at a first bogie-assembly pivot **84***p* at a rearward bogie-mount connection **92**. Trailing suspension element **70** is rotatably attached to forward suspension end **40** of trailing suspension arm **34** at trailing suspension-element pivot **86***p* and is rotatably attached to bogie-mount forward portion **50** at a second bogie-assembly pivot **88***p* at a forward bogie-mount connection **94**.

Leading suspension-element pivot **82***p* is sometimes herein referred to as first load- and ground-responsive suspension joint **82***p*, and trailing suspension-element pivot **86***p* is sometimes herein referred to as second load- and ground-responsive suspension joint **86***p*. The term "load- and ground-responsive suspension joint" is sometimes shortened to "suspension joint."

Within bogie mount **48** of bogie assembly **46** in track-module apparatus **10**, bogie-mount forward portion **50** and bogie-mount middle portion **54** are rotatably attached at a third bogie-assembly axis **90**.

Embodiment **10** includes a tensioning element **106** which provides attachment between leading suspension arm **24** and leading-idler assembly **30**. Leading-idler assembly **30** includes leading idler wheels **18** and a leading-idler axis **104** about which leading idler wheels **18** rotate. Leading-idler assembly **30** also includes a wheel linkage **120** at leading-idler axis **104**; in apparatus **10**, wheel linkage **120** is idler linkage **120**. Leading-arm distal end **28** is rotatably attached to idler linkage **120** at an idler offset axis **114** which is offset from leading-idler axis **104**.

A tensioning-element first end **108** of tensioning element **106** is rotatably attached to leading suspension arm **24** at a proximal tensioning pivot **112***p* at forward suspension end **40** between leading-arm distal end **28** and suspension-arm axis **44**. A tensioning-element second end **110** is rotatably attached to leading-idler assembly **30** at a distal tensioning pivot **116***p* offset from leading-idler axis **104**. Idler offset axis **114** is parallel to leading-idler axis **104** and angularly displaced therearound such that idler linkage **120** is a class **2** lever with idler offset axis **114** being the fulcrum thereof. Tension forces on track **22** are provided through idler wheels **18** by tensioning element **106** through the class **2** lever action of idler linkage **120** acted on by tensioning element **106**.

Suspension elements **68** and **70** and tensioning element **106** may provide both spring and damping forces. In some embodiments, such elements may be gas-filled and include a liquid-filled cavity to provide both types of forces for the suspension system. Such elements are well-known to those skilled in the art of vehicle suspension. Further description of suspension elements **68** and **70** is provided in the description of FIG. **9**.

FIGS. **7**A through **8**B illustrate the kinematics of track-module apparatus **10** under various operating conditions. Each such drawing is a side-elevation illustration of apparatus **10** under representative conditions to show the relative movement of the components of apparatus **10** under such conditions. FIGS. **7**A-**7**F illustrate the movement of vehicle track-module apparatus **10** as it traverses over a small bump **126** on the ground **124** along its path of travel. FIG. **7**A shows track-module apparatus **10** just prior to encountering bump **126**. FIG. **7**B shows apparatus **10** with its leading idler wheels **18** over bump **126**. FIG. **7**C shows apparatus **10** with leading bogie wheels **18** over bump **126**. FIG. **7**D shows apparatus **10** with middle bogie wheels **64** over bump **126**. FIG. **7**E shows apparatus **10** with trailing bogie wheels **60** over bump **126**. FIG. **7**F shows apparatus **10** with trailing idler wheels **20** over bump **126**.

FIG. **8**A is a side-elevation drawing of track-module apparatus **10** illustrating apparatus **10** as it traverses an uphill portion **128** of ground **124**. Similarly, FIG. **8**B is a side-elevation drawing of apparatus **10** illustrating apparatus **10** as it traverses a downhill portion **130** of ground **124**. Each of the drawings of FIGS. **7**A through **8**B illustrate idler wheels **18** and **20** and bogie wheels **56**, **60** and **64** all in contact with ground **124** in order to support some portion of the loads on apparatus **10**.

FIG. **9** is a schematic drawing of leading suspension element **68** and trailing suspension element **70** in a hydraulic circuit **134**. Suspension elements **68** and **70** each include cylinders hydraulic **136** containing hydraulic fluid **144** and gas-filled cylinders **138** containing gas **146** separated by pistons **140**. Hydraulic cylinders **136** and gas-filled cylinders **138** are movably sealed for relative movement by seals **142**, and gas-filled cylinders **138** and pistons **140** are movably sealed for relative movement by another set of seals **142** such that the volumes of hydraulic fluid **144** and gas **146** may both change under loads which are applied across suspension elements **68** and **70**. In such components, gas **146** is typically nitrogen but other gases may be used.

Hydraulic cylinders **136** are interconnected by a hydraulic conduit **148** placing suspension elements **68** and **70** in a common hydraulic circuit such that the pressures in suspension elements **68** and **70** are equal. Gas **146** in gas-filled cylinders **138** enables suspension elements **68** and **70** to provide spring forces to the suspension system of apparatus **10** while hydraulic fluid **144** flowing through hydraulic conduit **148** enables suspension elements **68** and **70** to provide damping forces to the suspension system of apparatus **10**.

Hydraulic circuit **134** also includes an external accumulator **150** connected to hydraulic conduit **148** by an accumulator conduit **156**. Accumulator **150** includes both hydraulic fluid **144** and gas **146** in sealed separation from one another by an accumulator piston **152** movably sealed within accumulator **150** by accumulator seal **154**. Gas **146** within accumulator **150** provides additional spring force to the suspension system of apparatus **10** while hydraulic fluid **144** flowing through accumulator conduit **156** and hydraulic conduit **148** provides additional damping force to suspension system of apparatus **10**.

Suspension elements **68** and **70** and tensioning element **106** may provide suspension forces which are variable. For example, the damping forces may depend on the direction of the movement (extension or contraction) of the element in order to provide a specific desired suspension performance.

The operation of the components of hydraulic circuit **134** are well-known to those skilled in mechanical systems. FIG. **9** is intended only to be schematic. For example, the functions of accumulator piston **152** and accumulator seal **154** may be provided by a membrane, a bladder or other similar component. In similar fashion, the components of suspension elements **68** and **70** may also be different from those described above while providing similar operation of suspension elements **68** and **70**.

FIG. **10** is a schematic diagram of the embodiment of FIGS. **1**A and **1**B, illustrating a supported load FL and a set of five resulting wheel loads F**1** through F**5**. The load on leading wheels **18** is referred to as F**1**; the load on leading bogie wheels **56** is referred to as F**2**; the load on middle bogie wheels **64** is referred to as F**3**; the load on trailing bogie wheels **60** is referred to as F**4**; and the load on trailing wheels **20** is referred to as F**5**. Since all of supported load FL acts on suspension-arm axis **44**, FIG. **10** shows FL at such location in the schematic diagram of FIG. **10**.

The load FL supported by track-module apparatus **10** may have both vertical and horizontal components depending on the specific operational situation. These include at least the following: (a) the portion of the vehicle weight supported by apparatus **10**; (b) pulling forces when the vehicle is pulling a load; and (c) braking forces which in an emergency braking situation may be quite high. Also, of course, each of the resulting forces F**1** through F**5** may also have both vertical and horizontal components, and all of these forces vary with the slope of the ground being traversed.

FIGS. **11** through **14** are side-elevation drawings (similar to FIG. **4**) illustrating several alternative embodiments **10***a* through **10***d*, respectively, of the vehicle track-module apparatus. In each of FIGS. **11**-**14**, the same reference numbers are used for components similar to those of track-module apparatus **10**.

FIG. **11** is a side-elevation drawing (similar to FIG. **4**) of a first alternative embodiment **10***a* of the vehicle track-module apparatus. Embodiment **10***a* is similar to embodiment **10** except that middle bogie wheels **64** have been eliminated with corresponding changes in other components to accommodate such modification. A track module similar to first alternative embodiment **10***a* may be used to reduce complexity and cost when compared to embodiment **10** and/or may be used when the distance between the leading and trailing wheels needs to be shorter than is provided by embodiment **10**.

FIG. **12** is a side-elevation drawing (similar to FIG. **4**) of a second alternative embodiment **10***b* of the vehicle track-module apparatus. Embodiment **10***b* is similar to first alternative embodiment **10***a* except that tensioning element **106** has been eliminated and leading-idler assembly **30** primarily includes only leading idler wheels **18**. A track module similar to second alternative embodiment **10***b* may be used to reduce complexity and cost when compared to embodiment **10**. Similar to first embodiment **10***a*, second embodiment **10***b* may also provide a shorter distance between the leading and trailing wheels if such a configuration is desirable.

FIG. **13** is a side-elevation drawing (similar to FIG. **4**) of a third alternative embodiment **10***c* of the vehicle track-module apparatus. Embodiment **10***c* is similar to embodiment **10** except that tensioning element **106** has been eliminated and leading-idler assembly **30** primarily includes only leading idler wheels **18**. A track module similar to third alternative embodiment **10***c* may be used to reduce complexity and cost when compared to embodiment **10**.

FIG. **14** is a side-elevation drawing (similar to FIG. **4**) of a fourth alternative embodiment **10***d* of the vehicle track-module apparatus. Embodiment **10***d* is similar to third alternative embodiment **10***c* except that third bogie-assembly axis **90** has been eliminated with corresponding changes in other components to accommodate such modification. A track module similar to fourth alternative embodiment **10***d* may be used to reduce complexity and cost when compared to embodiment **10**. In the case of fourth embodiment **10***d*, a degree-of-freedom within bogie assembly **46** has been removed; under certain operational conditions such as travel mainly on generally even terrain, this reduction in compliance may be acceptable.

FIG. **15**A is side-elevation drawing of portions of vehicle track-module apparatus **10** to illustrate the detail of tensioning-element first end **108** of tensioning element **106**. FIG. **15**B is a sectional view (section A-A) as indicated in FIG. **15**A. Section A-A passes through proximal tensioning pivot **112***p* at the rotatable attachment between tensioning element **106** and leading suspension arm **24**.

FIG. **15**C is a further enlargement of a portion of FIG. **15**B to show even more detail of proximal tensioning pivot **112***p*. As described above, certain pivot points within apparatus **10** involve structures which provide more than one degree-of-freedom of rotation. In the naming convention used herein, the word "pivot" is used for such more than one degree-of-freedom connections. Within apparatus **10**, these include **82***p*, **84***p*, **86***p*, **88***p*, **112***p* and **116***p*, and FIGS. **15**A-**15**C are used to illustrate one such pivot. In embodiment **10**, all such pivots are spherical bearings as is shown for pivot **112***p*.

Referring to FIG. **15**C, proximal tensioning pivot **112***p* includes a spherical bearing which includes a ball **112***b* which rotates in a socket **112***s* on leading suspension arm **24**. A mechanical connector **112***c* holds ball **112***c* in socket **112***s*.

By using the inventive structure of the various embodiments of track-module apparatus disclosed herein and by selecting the dimensions of the various components, a track-module designer is able to set the load distribution on the ground-engaging wheels to meet the requirements of a particular vehicle application. For example, it may be desirable to have the leading or trailing wheels take somewhat different percentages of the load on the vehicle. And often it is desirable, when the apparatus has more than one bogie-wheel axle, to have each of the bogie-wheel axles support substantially the same vehicle load. A set of linkage dimensions can be chosen to distribute the load supported by the bogies as desired.

Kinematic analysis methods well-known to those skilled in the art of mechanical systems can be used to evaluate the load-distribution performance of a specific set of linkage dimensions in apparatus **10**. In the example described below and in FIGS. **17**A and **17**B, such analysis was used to compute the load distribution under a set of different load conditions. Referring to the schematic diagram of FIG. **10**, the dimensions are represented by the following notation. A horizontal dimension includes the letter "H" followed by two reference numbers separated by a colon. Thus, H**44**:**118** is the horizontal distance from suspension axis **44** to trailing-idler axis **118**. The letter "V" indicates a vertical dimension, and the letter "D" a diameter. FIG. **17**A summarizes a set of dimensions for a representative configuration of track-module apparatus **10** with suspension elements **68** and **70** in common hydraulic circuit **134**.

FIG. **17**B summarizes the results of analysis of the representative example of FIG. **17**A. As can be seen, in this example, the loads F**2**, F**3** and F**4** on bogie wheels **56**, **64** and **60**, respectively, are and remain evenly distributed among the bogie wheels, and the addition of various portions of the total loading from vehicle weight, track tension, braking and pull cause very modest changes to the load distribution percentages.

The power source for the track-module apparatus is not limited to a rotating power shaft of the vehicle. Other power-source configurations are contemplated, such as a hydraulic motor or other power source on the vehicle or a mechanical, hydraulic or other power source directly mounted on the apparatus itself.

FIG. **18** is perspective drawing of a fifth alternative track-module embodiment **200**. FIG. **19** is a side elevation drawing of the track-module embodiment **200**. Track-module embodiment **200** includes many of the same components as track-module apparatus **10** as shown in FIGS. **1**-**6**B, and thus FIGS. **18** and **19** do not repeat many reference numbers from these previous figures. Only those components which are different from previously-described embodiments and certain others for clarity of description are marked with reference numbers.

As in previous track-apparatus embodiments, embodiment **200** includes bogie-suspension apparatus which includes bogie assembly **46**, leading suspension element **68**, and trailing suspension element **70**. Bogie assembly **46** includes bogie mount **48** and a plurality of bogie wheels (**56**, **60** and **64** in embodiment **200**). Bogie-mount **48** includes bogie-mount arm **102**, bogie-mount forward portion **50**, bogie-mount rearward portion **52**, and bogie-mount middle portion **54**. Embodiment **200** also includes axes and pivots as previously described in other embodiments in this document.

Track-module embodiment **200** differs from all of the previously-described embodiments of track-module apparatus in that movements of leading suspension element upper end **68**U at first suspension joint **82***p* and trailing suspension element upper end **70**U at second suspension joint **86***p* are interdependent. Such interdependence is brought about by track-module apparatus **200** including unitary leading and trailing idler arms **202** (unitary structure **202**). The unitary character of such arm structure is indicated by reference number **202** on both leading and trailing portions of unitary structure **202**. As best seen in FIG. **18**, the leading and trailing portions of the unitary structure **202** are rigidly connected to form a single structure with leading and trailing portions rotatably attached to frame **12** at suspension-arm axis **44**. Since first suspension joint **82***p* and second suspension joint **86***p* are on opposite sides of unitary structure **202** with respect to suspension arm axis **44**, upward movement of one of the suspension joints occurs with downward movement of the other. The relative magnitudes of the movements are determined by the distances of each suspension joint from suspension-arm axis **44**.

Leading suspension element lower end **68**L at first bogie-assembly pivot **84***p* and trailing suspension element lower end **70**L at second bogie-assembly pivot **88***p* connect bogie mount **48** at rearward bogie-mount connection **92** and forward bogie-mount connection **94**, respectively.

In embodiment **200**, bogie assembly **46** includes third load- and ground-responsive suspension joint **78** which is rotatably attached to unitary structure **202** and thus movements of suspension joint **78** and first and second suspension joints are all interdependent. In embodiment **200** as in the previously-described embodiments, suspension joint **78** only transmits lateral forces between unitary structure **202** and bogie assembly **46**.

In embodiment **200**, first and second suspension joints **82***p* and **86***p* and first and second bogie-assembly pivots **84***p* and **88***p* all utilize spherical bearings as previously described. Although single degree-of-freedom bearings may also be used, but it is preferred that these joints/pivots each provide a plurality of rotational degrees-of-freedom.

While the principles of this invention are shown and described here in connection with specific embodiments, it is to be understood that such embodiments are by way of example and are not limiting.

The invention claimed is:

1. Track-module bogie-suspension apparatus for attachment to a track module having a frame, a drive wheel and an endless track, comprising:

a bogie assembly having a bogie mount, at least one leading bogie ground-engaging wheel and at least one trailing bogie ground-engaging wheel thereon, and forward and rearward bogie-mount connections, the bogie mount including:

a bogie-mount forward portion having the at least one leading bogie wheel rotatably attached thereto at a leading bogie axis, the bogie-mount forward portion including the forward bogie-mount connection; and

a bogie-mount rearward portion having the at least one trailing bogie wheel rotatably attached thereto at a trailing bogie axis, the bogie-mount rearward portion including the rearward bogie-mount connection;

first and second load- and ground-responsive suspension joints spaced from one another in a forward/rearward direction; and

leading and trailing suspension elements each having an upper end and a lower end, the upper ends of the leading and trailing suspension elements rotatably attached to the first and second suspension joints, respectively, and the lower ends thereof rotatably attached to the rearward and forward bogie-mount connections, respectively.

2. The bogie-suspension apparatus of claim **1** further including a third load- and ground-responsive suspension joint and wherein the bogie assembly further includes a bogie-assembly arm rotatably attached (a) at a bogie-assembly arm distal end to the third suspension joint and (b) at a bogie-assembly arm proximal end to the bogie mount.

3. The bogie-suspension apparatus of claim **2** further including rotatable attachments of the leading and trailing suspension elements at the first and second suspension joints, respectively, which are configured to permit rotation having at least two degrees-of-freedom, and the rearward and forward rotatable bogie-mount connections are configured to permit rotation having at least two degrees-of-freedom.

4. The bogie-suspension apparatus of claim **1** including at least two leading bogie wheels and at least two trailing bogie wheels and wherein the leading bogie axis rotates on a leading bogie roll axis perpendicular thereto and the trailing bogie axis rotates on a trailing bogie roll axis perpendicular thereto.

5. The bogie-suspension apparatus of claim **1** wherein the bogie-mount forward and rearward portions are rotatably attached at a third bogie-assembly axis.

6. The bogie-suspension apparatus of claim **1** wherein the bogie mount further includes a bogie-mount middle portion having at least one middle bogie wheel attached thereto at a middle bogie axis.

7. The bogie-suspension apparatus of claim **6** including at least two leading bogie wheels, at least two trailing bogie wheels, and at least two middle bogie wheels and wherein:

the leading bogie axis rotates on a leading bogie roll axis perpendicular thereto;

the middle bogie axis rotates on a middle bogie roll axis perpendicular thereto; and

the trailing bogie axis rotates on a trailing bogie roll axis perpendicular thereto.

8. The bogie-suspension apparatus of claim **7** wherein the bogie-mount forward and middle portions are rotatably attached at a third bogie-assembly axis.

9. The bogie-suspension apparatus of claim **1** wherein the leading and trailing suspension elements each include gas-filled components to provide spring force.

10. The bogie-suspension apparatus of claim **9** wherein the leading and trailing suspension elements each further include hydraulic components.

11. The bogie-suspension apparatus of claim **10** wherein the leading and trailing suspension elements are on a common hydraulic circuit.

12. The bogie-suspension apparatus of claim **11** further including an external accumulator hydraulically connected to the common hydraulic circuit.

13. The bogie-suspension apparatus of claim **1** including plural bogie wheels and wherein the bogie wheels have diameters which are substantially the same as each other.

14. The bogie-suspension apparatus of claim **1** wherein the first and second load- and ground-responsive suspension joints are independently responsive to load and ground variations.

15. The bogie-suspension apparatus of claim **14** further including a third load- and ground-responsive suspension joint and wherein the bogie assembly further includes a bogie-assembly arm rotatably attached (a) at a bogie-assembly arm distal end to the third suspension joint and (b) at a bogie-assembly arm proximal end to the bogie mount, the movement of the first and third suspension joints being interdependent.

16. The bogie-suspension apparatus of claim **14** further including rotatable attachments of the leading and trailing suspension elements at the first and second suspension joints, respectively, which are configured to permit rotation having at least two degrees-of-freedom, and the rearward and forward rotatable bogie-mount connections are configured to permit rotation having at least two degrees-of-freedom.

17. The bogie-suspension apparatus of claim **14** including at least two leading bogie wheels and at least two trailing bogie wheels and wherein the leading bogie axis rotates on a leading bogie roll axis perpendicular thereto and the trailing bogie axis rotates on a trailing bogie roll axis perpendicular thereto.

18. The bogie-suspension apparatus of claim **14** wherein the bogie-mount forward and rearward portions are rotatably attached at a third bogie-assembly axis.

19. The bogie-suspension apparatus of claim **14** wherein the bogie mount further includes a bogie-mount middle portion having at least one middle bogie wheel attached thereto at a middle bogie axis.

20. The bogie-suspension apparatus of claim **19** including at least two leading bogie wheels, at least two trailing bogie wheels, and at least two middle bogie wheels and wherein:

the leading bogie axis rotates on a leading bogie roll axis perpendicular thereto;

the middle bogie axis rotates on a middle bogie roll axis perpendicular thereto; and

the trailing bogie axis rotates on a trailing bogie roll axis perpendicular thereto.

21. The bogie-suspension apparatus of claim **20** wherein the bogie-mount forward and middle portions are rotatably attached at a third bogie-assembly axis.

22. The bogie-suspension apparatus of claim **1** wherein movements of the first and second load- and ground-responsive suspension joints are interdependent.

23. The bogie-suspension apparatus of claim **22** further including a third load- and ground-responsive suspension joint and wherein the bogie assembly further includes a bogie-assembly arm rotatably attached (a) at a bogie-assembly arm distal end to the third suspension joint and (b) at a bogie-assembly arm proximal end to the bogie mount, the movement of the suspension joints being interdependent.

24. The bogie-suspension apparatus of claim **22** further including rotatable attachments of the leading and trailing suspension elements at the first and second suspension joints, respectively, which are configured to permit rotation having at least two degrees-of-freedom, and the rearward and forward rotatable bogie-mount connections are configured to permit rotation having at least two degrees-of-freedom.

25. The bogie-suspension apparatus of claim **22** including at least two leading bogie wheels and at least two trailing bogie wheels and wherein the leading bogie axis rotates on a leading bogie roll axis perpendicular thereto and the trailing bogie axis rotates on a trailing bogie roll axis perpendicular thereto.

26. The bogie-suspension apparatus of claim **22** wherein the bogie-mount forward and rearward portions are rotatably attached at a third bogie-assembly axis.

27. The bogie-suspension apparatus of claim **22** wherein the bogie mount further includes a bogie-mount middle portion having at least one middle bogie wheel attached thereto at a middle bogie axis.

28. The bogie-suspension apparatus of claim **27** including at least two leading bogie wheels, at least two trailing bogie wheels, and at least two middle bogie wheels and wherein:

the leading bogie axis rotates on a leading bogie roll axis perpendicular thereto;

the middle bogie axis rotates on a middle bogie roll axis perpendicular thereto; and

the trailing bogie axis rotates on a trailing bogie roll axis perpendicular thereto.

29. The bogie-suspension apparatus of claim **28** wherein the bogie-mount forward and middle portions are rotatably attached at a third bogie-assembly axis.

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